FINAL REPORT

Demonstration of UXO-PenDepth for the Estimation of Projectile Penetration Depth

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14. ABSTRACT

The software UXO-PenDepth is a physics-based tool that uses the physical characteristics and trajectory of a projectile to estimate projectile penetration depth for a variety of soil types, moisture states, and firing conditions. It provides a reliable means for the munitions response community and regulators to estimate projectile penetration depth. The values of the reported UXO recovery depths are generally within the estimates obtained using UXO-PenDepth with the minimum firing parameters. Although the majority of the recovered UXO are within the UXO-PenDepth minimum firing parameter estimate, it is important to note that the majority of the recovery depths for a given UXO category are shallower than the shallowest UXO-PenDepth penetration estimate. Possible discrepancies could be attributed to: 1) the modeled UXO in this study are not representative of the recovery data, 2) differences in subsurface soil structure and soil parameters, 3) variations in firing parameters and methods of firing, and 4) UXO movement after initial penetration and prior to recovery.

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EXECUTIVE SUMMARY

The use of projectile penetration estimates derived from modeling programs is limited, primarily because there is no reliable, physics-based program available to the munitions response community or regulators. The software UXO-PenDepth was developed to address the need for a physics-based tool that uses the physical characteristics and trajectory of a projectile to estimate projectile penetration depth. It is a 3-D projectile penetration code that calculates the trajectory of a rigid axisymmetric projectile impacting a soil target. Input parameters include munitions type, impact velocity, impact angle, subsurface soil structure (layers and thicknesses), and a soil penetrability index. The soil penetrability index is an empirical value and typically ranges between 5 and 12 for sand-silt-clay soil mixtures having dry to wet moisture states. Both half-space and two-layer soil scenarios are presented. The soil scenarios include sand, silt, and clay half-spaces with varying soil penetrability indexes that represent dry, moderate, and wet moisture conditions. The two-layer scenarios are combinations of sand, silt, and clay with different first layer thicknesses. Depth penetration range (DPR) plots are generated that provide a summary of projectile penetration depth curves over a range of impact velocities and impact angles.

For the sand, silt, and clay half-spaces with SNUM 5 to 12 (dry to wet moisture states) and ordnance size 81-mm and smaller plus the 105-mm HEAT, the depth of penetration achieved using minimum impact parameters is < 1 m; penetration depths achieved using maximum impact parameters is < 2.4 m.

Two general observations were noted for the two-layer soil models. Firstly, depth of penetration increases as first-layer thickness increases when the soil resistance of the first layer is less than the soil resistance of the second layer, and penetration depth is less than or equal to the half-space penetration depth. Secondly, depth of penetration decreases as first-layer thickness increases when soil resistance of the first layer is greater than the second layer soil resistance, and penetration depth is greater than the half-space penetration depth.

The values of the reported UXO recovery depths are generally within the estimates obtained using UXO-PenDepth with the minimum firing parameters. Although the majority of the recovered UXO are within the UXO-PenDepth minimum firing parameter estimate, it is important to note that the majority of the recovery depths for a given UXO category are shallower than the shallowest UXO-PenDepth penetration estimate. Possible discrepancies could be attributed to: 1) the modeled UXO in this study are not representative of the recovery data, 2) differences in subsurface soil structure and soil parameters, 3) variations in firing parameters and methods of firing, and 4) UXO movement after initial penetration and prior to recovery.

1.0 INTRODUCTION

Presently, no information regarding projectile penetration depth is considered when planning munitions response efforts. The reason for this is that there is no reliable or acceptable method readily available to the unexploded ordnance (UXO) community for modeling projectile penetration. Lack of penetration information can result in inaccurate time and cost projections, and the clearance of areas to depths greater than penetration capabilities of a projectile. This report describes the software UXO-PenDepth, which provides realistic depth of projectile penetration estimates for a variety of soil types, moisture states, and firing conditions.

The U.S. Army Corps of Engineers (USACE) manual "Military Munitions Response Actions," EM 1110-1-4009 (15 June 2007), is the standard document used for planning geophysical response actions at an UXO contaminated site. It states that, "The maximum possible depth of MEC [munitions and explosives of concern] is an important consideration in the selection of an appropriate detection system." It also states an important fact, that some MEC can penetrate deeper than geophysical systems can reliably detect. The document acknowledges that there is no consensus among the Military Munitions Response Program (MMRP) community regarding ordnance penetration. The primary reason for this is because there is currently no method for estimating projectile penetration openly available to the MMRP community. As a result, sites contaminated with UXO are often cleared to depths greater than any recovered UXO. These specified clearance depths are commonly two or more times deeper than the deepest UXO recovered. The cost of UXO clearance operations is typically the greatest portion of UXO site remediation costs. The software UXO-PenDepth was developed to address the need for a physics-based tool that uses the physical characteristics and trajectory of a projectile to estimate projectile penetration depth.

1.1 BACKGROUND

The software UXO-PenDepth uses a modified version of the theoretical development in the Response Surface Map (RSM) module of the software PENCRV3D (Adley et al., 1999) developed by the U.S. Army Engineer Research and Development Center (ERDC). The program PENCRV3D belongs to a suite of codes, PENCURV+ (Adley et al., 2006), which has its beginnings in 1975 with development continuing to the present. The code has progressed from a one-dimensional to three-dimensional (3-D) projectile penetration code, i.e., the projectile and its trajectory modeled precisely in all three planes. PENCRV3D Version 2.0 received accreditation from the Joint Technical Coordinating Group for Munitions Effects (JTCG/ME) in August 2001. The accreditation process included verification and validation (V&V) by a subject matter expert (SME) other than the developers. The assessment included issues of algorithm choice, data requirements, assumptions, limitations, errors, user interface, and the implications of these to the end users. The SME was involved in the V&V and recommended accreditation of PENCRV3D to the JTCG/ME.

While the current PENCURV codes were primarily developed to address projectile penetration into concrete structures for application in combat situations, the predecessor developments leading to PENCURV were directed to analyses of projectile penetration in soil and rock. The current PENCURV codes include empirical solutions for soils penetration that

were originally developed by Sandia National Laboratories (Young, 1972). The RSM technique has been used successfully by private defense contractors and government agencies for penetration analysis (Patterson, 2006). There have been many years of research invested in the development of the theory that comprises PENCURV+ that has been successfully validated through numerous pre- and post-test penetration predictions for a variety of applications. The results of this research have been transferred to the prototype UXO-PenDepth code.

Within UXO-PenDepth, there are three sets of input parameters that are required: impact conditions (Fig. 1a), penetrator properties, and target properties. The impact conditions that need to be defined are projectile orientation and impact velocity. The algorithm has been evaluated against data for impact velocities ranging from 38 m/sec to 1,220 m/sec (125 ft/sec to 4,000 ft/sec), obliquities from 0 to 50 degrees, and angles of attack up to about 8.5 degrees. The impact conditions of many projectiles, mortars, and rockets, from 20 mm to 155 mm, are within these parameter ranges. Input for the penetrator includes weight, transverse moments of inertia, and projectile geometry. The penetrator is selected from the database provided with the software. The algorithm has been evaluated against data for projectiles ranging in mass from 0.9 kg to 2,268 kg (2 lbs to 5,000 lbs) with diameters from 13 mm to 457 mm (0.5 in. to 18 in.), and nose shapes from caliber radius head (CRH) (Fig. 1b) of 2 to 9.25. A limited database of projectiles of interest is provided with the UXO-PenDepth software. There is no arbitrary projectile capability in UXO-PenDepth, although there is a scaling capability, i.e., a projectile in the database can be used to generate one that has a similar shape but different size. Input for the target includes target geometry and material. Target geometry is a homogeneous or layered earth, whereas for the target material the user inputs a penetrability index for a soil layer. The algorithm has been evaluated against data for targets with penetrability indexes from 2.5 to 15, corresponding to well-cemented coarse sand and gravel to moist top soil or medium-stiff clay with some sand.

The history behind the development of the penetration algorithm used in UXO-PenDepth, and evaluation and validation of the algorithm against data for the required input parameter sets (impact conditions, penetrator properties, and target properties) supports the fact that the algorithm is at a state of maturity sufficient for demonstration for UXO applications.

1.2 OBJECTIVE OF THE DEMONSTRATION

This work demonstrates the functional capabilities of the software UXO-PenDepth for estimating ordnance penetration depths. Scenarios involving different soil types, moisture conditions, and layer models show how the depth of penetration varies over a range of impact velocities and impact angles. The penetration depths are realistic and comparable to those reported from recovery sites.

1.3 REGULATORY DRIVERS

The Department of Defense (DoD) has mandated the clean up of federal lands contaminated with UXO. Often times regulators require a removal contractor to provide some form of documentation, other than historical dig data, as assurance that a site has been cleared to an appropriate depth for the munitions thought to be present. Presently, there is no reliable technique for estimating the penetration depth of munitions, and therefore it is difficult to fulfill

the regulator's request. UXO-PenDepth is a physics-based program that can be used to estimate munitions penetration depth during the munitions response process.

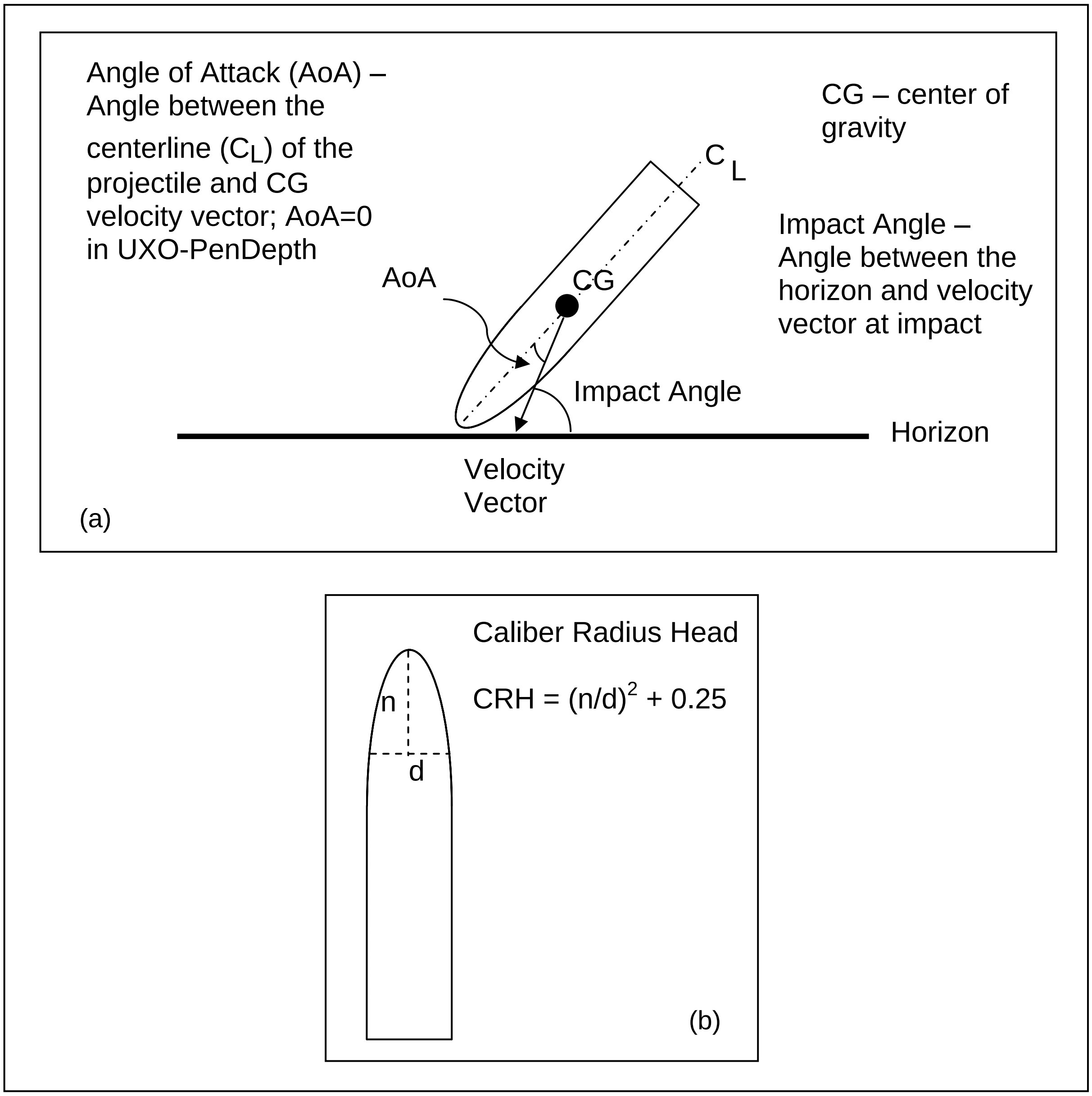


Figure 1. Description of projectile impact parameters (a) and caliber radius head (b).

2.0 TECHNOLOGY

2.1 TECHNOLOGY DESCRIPTION

UXO-PenDepth is a 3-D projectile penetration code that calculates the trajectory of a rigid axisymmetric projectile impacting soil targets (Simms et al., 2006). Six equations are required to describe the general 3-D motion, i.e., three translational and three rotational. UXO-PenDepth uses a differential-area-force-law (DAFL) type of formulation as was originated by AVCO Corporation (Henderson and Stephens, 1972). The code divides the projectile longitudinally then circumferentially into a mesh of elements making a differential area dA_{ij} for an i^{th} longitudinal element and j^{th} circumferential element (Fig. 2) on the projectile's surface. A normal stress, which represents the penetration resistance of the target, is then calculated and applied to the center of each element. The force contribution from each element is obtained by multiplying the magnitude of the stress by the differential area dA_{ij} of that element. The total forces used in the translational equations of motion are then obtained by summing the elemental force contributions over all the elements. The total moments used in the rotational equations of motion are calculated by multiplying the elemental forces by the appropriate moment arm and summing the elemental moment contributions over all the elements. This algorithm represents a simple spatial integration scheme.

Once the parameters in the equations of motion are determined for a given time *t*, the equations are integrated by using a finite difference approach. The finite-difference temporal integration scheme solves for the updated position and velocity of the projectile at time $t+\Delta t$, where Δt represents the time step size. The spatial and temporal integration schemes are repeated until the projectile comes to rest, i.e., until the updated value of velocity is less than a small specified value.

The final step in the development of the code involves the derivation of a methodology that models the penetration resistance of the target material. This step is completed by developing a penetration resistance constitutive model that expresses the penetration resistance of the material (represented by the normal stress σ_s) as a function of the material properties of the target material and the relevant kinematic and kinetic variables that define the state of the projectile as a function of time. The starting point for the development of penetration resistance equations has traditionally been cavity expansion solutions, which can be expressed in the following form:

$$\sigma_s = a_s + b_s V + c_s V^2 , \qquad (1)$$

where the parameters a_s, b_s and c_s are functions of the material properties, and V is the cavity expansion velocity, which is related to the current velocity of the projectile by the nature of the projectile penetration problem. Noting that the strength of soils is dependent on the confining pressure, and the confining pressure in a soil mass is a linear function of the vertical depth to the soil element under consideration, it appears that the penetration resistance should be a linear function of the vertical position (Z) of the projectile. Observations of soil penetration data led to

the additional criteria that the axial force versus time plot should have the form of a step-pulse. In addition to the aforementioned criteria, it is also assumed that the penetration resistance

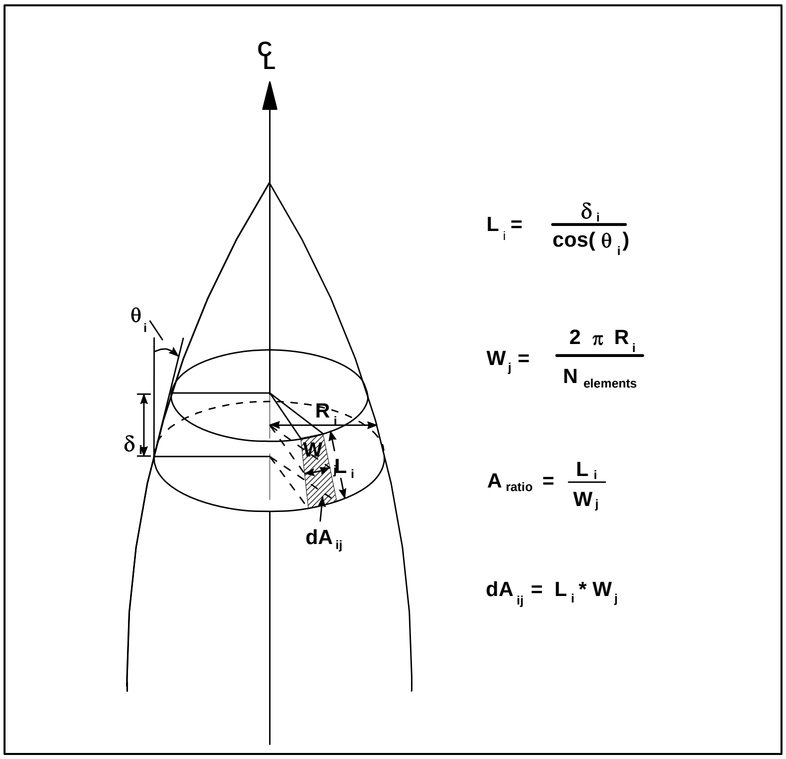


Figure 2. Differential area dA_{ij}.

should exhibit a linear dependence on the projectile velocity (V). A penetration resistance equation that satisfies the above criteria can be developed by making the following modifications to Equation (1):

$$\sigma_s = a_s + b_s V + c_s Z \ . \tag{2}$$

Finally, rather than using standard engineering properties to describe the target, the decision was made to use a single penetrability variable (SNUM) to describe the target material properties. This decision was based on the fact that the equation for penetration depth developed by Young (1972) successfully employed this approach. Young (1972) compiled a table of SNUM values associated with a variety of material types. Therefore, the parameters a_s, b_s and c_s are assumed to be functions of the penetrability variable (SNUM).

The aforementioned considerations led to the development of the following UXO-PenDepth penetration resistance equation (shown in the consistent set of English units defined by using pounds, seconds, inches):

$$\sigma_s = \sqrt{\frac{v_{ij}^N}{v_{ij}}}\left(\frac{1.023\times10^4}{R_i\,SNUM} + \frac{2.167\,v_{ij}\sqrt{R_i}}{SNUM} - \frac{532.7\,Z_{ij}}{SNUM^2}\sqrt{\frac{v_{ij}^N}{v_{ij}}}\right), \quad (3)$$

where R_i is the average radius of the i^{th} longitudinal element in inches, Z_{ij} is the vertical distance from target surface to the center of differential area dA_{ij} in inches, v_{ij} is the resultant velocity at the center of dA_{ij} in inches per second, and v_{ij}^N is the normal component of velocity at the center of dA_{ij} in inches per second.

The *SNUM* variable in Equation (3) can be obtained directly from previous penetration data for a given target, or it can be estimated from data for geologically similar targets using Table 1. A more comprehensive derivation of Equation (3), as well as validation simulations, can be found in the reports by Bernard (1978) and Bernard and Creighton (1978).

Table 1. Typical soil penetrability index for natural earth materials (Defense Special Weapons Agency, 1998).

Soil Index SNUM	Materials
2-3	Massive gypsite deposits. Well-cemented coarse sand and gravel. Caliche, dry. Frozen moist silt or clay.
4-6	Medium dense, medium or coarse sand, no cementation, wet or dry. Hard, dry, dense silt or clay. Desert alluvium.
8-12	Very loose fine sand, excluding topsoil. Moist stiff clay or silt, medium dense, less than about 50% sand.
10-15	Moist topsoil, loose, with some clay or silt. Moist medium-stiff clay, medium dense, with some sand.
20-30	Loose moist topsoil with humus material, mostly sand and silt. Moist to wet clay, soft, low shear strength.
40-50	Very loose dry sandy topsoil. Saturated very soft clay and silts, with very low shear strengths and high plasticity (Great Salt Lake Desert and bay mud at Skaggs Island). Wet lateritic clays.
10,000	Air

2.2 TECHNOLOGY DEVELOPMENT

2.2.1 SOIL PENETRABILITY INDEX

As stated previously, the soil penetrability index SNUM is an empirical parameter. The values for SNUM listed in Table 1 are based on over 500 full-scale earth penetration tests (Young, 1972). The tests were performed in a variety of soil types, ranging from dry, loose sands to saturated, high plasticity clays. The penetrability of a soil is primarily dependent on soil shear strength, density and moisture content. In general, depth of penetration increases as shear

strength decreases; decreases as density increases; and increases as moisture content increases. Some general guidelines (Young, 1997) regarding selection of SNUM are given below:

1) Except for marine-type clay sediments, it is unusual for soils at depth greater than 15 m to be softer than SNUM=15;
2) Except for cemented soils, such as cemented sand or caliche, it is unusual for soils to be harder than SNUM=5;
3) The penetrability of clay and silt is highly dependent on moisture content;
4) The penetrability of sand is almost independent of moisture content. Only about 20% to 30% clay and/or silt are required to make a sand/silt/clay material dependent on water content;
5) Ease of soil excavation by hand or shovel is not a good guide for penetrability. For example, a stiff clay is hard to dig and easy to penetrate, but a loose sand is easy to dig and hard to penetrate.

2.2.2 PROJECTILE INPUT MODEL GENERATION

Generation of an input model for a projectile based on its technical specifications is crucial for simulating proper motion and penetration behavior. An input file requires detailed information describing dimensions of the outer shape of the projectile, inner filler material shape and distribution, weights of the projectile and fill, case material type, and nose shape. From this information, the center of gravity and moments of inertia can be determined for use in calculating the projectile trajectory. Some of the required information can be obtained from technical manuals, however, it was necessary to gain access to secure databases to complete the projectile technical descriptions. The secure databases included MIDAS (Munition Item Disposal Action System), maintained by the U.S. Army Defense Ammunition Center (DAC), and JEDMICS (Joint Engineering Data Management Information and Control System). Once the input files are created, they can be stored in the program's database for repeated use.

A scaling option is available within UXO-PenDepth that scales a given projectile to maintain the same shape and weight distribution so that the center of gravity remains in the same position relative to the nose tip. This feature is useful for generating input files similar to those in the database, but with different dimensions. A scale model input file is available in the munitions database that represents a 1/7 scale semi-armor piercing (SAP) 2,000 pound projectile. The 1/7 SAP model (Fig. 3) represents a projectile 35.56 cm in length, diameter of 50.8 mm, and weight of 2.35 kg (5.17 lb). It is convenient for performing parametric studies.

2.2.3 PARAMETER INFLUENCES ON TRAJECTORY

Before proceeding with the projectile penetration study, it is instructional to observe the influence of the input parameters on the subsurface trajectory of a projectile. The soil penetrability (SNUM), impact velocity, and impact angle were varied separately to determine the effect on the trajectory of a 1/7 SAP. Figure 4 shows the results of each model simulation. Varying the soil penetrability (Fig. 4a) and impact velocity (Fig. 4b) only lengthens the trajectory path, without any variation in the trajectory. A change in impact angle (Fig. 4c) causes a change in trajectory, as expected, with depth of penetration increasing as impact angle increases.

Bernard and Creighton (1978) obtained similar results in a study of non-normal impact of a projectile in soil and rock. They modeled a 136.1-kg (300-lb) projectile (length 121.92 cm, diameter 152.4 mm). In addition to varying the soil penetrability, impact velocity, and impact angle, they scaled the projectile (keeping the center of gravity in the same relative position) and found that the trajectory was consistent, with the primary effect being a lengthening of the travel path.

UXO-PenDepth does not model a "J-hook" trajectory, i.e., an upward curving of the trajectory path in the subsurface. The J-hook phenomenon is generally restricted to larger ordnance that have a tapered aft body and restricted to soils with SNUM>6 (Adley, et al., 2006).

Figure 3. 1/7 SAP scale model (length 35.56 cm, diameter 50.8 mm, weight 2.35 kg).

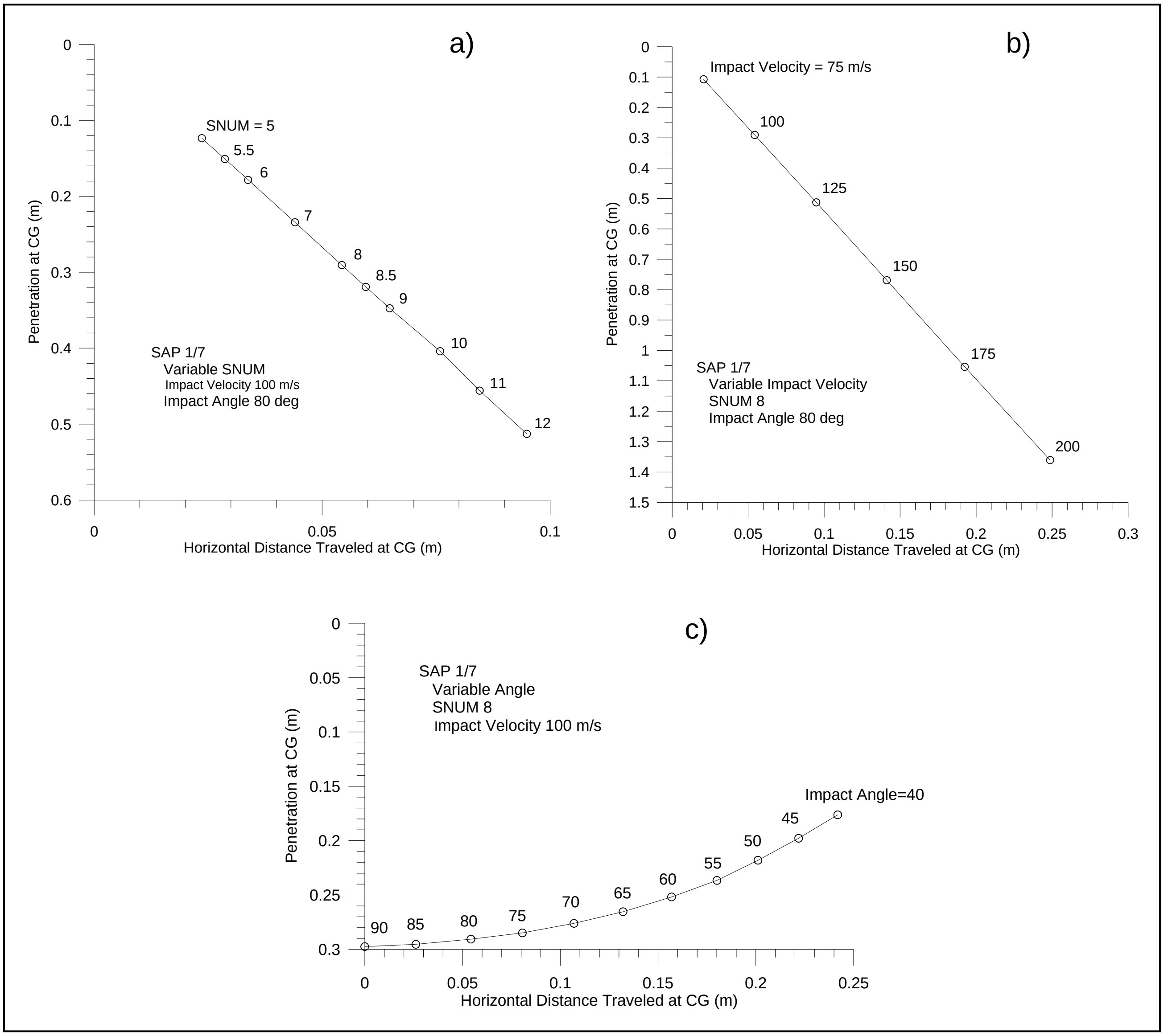


Figure 4**.** Influence of soil resistance parameter SNUM (a), impact velocity (b), and impact angle (c) on subsurface trajectory of a projectile.

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

The algorithm for estimating penetration resistance has undergone a rigorous validation process. There is a concern regarding the difference between penetration depth and burial depth. UXO-PenDepth calculates the initial penetration depth of a projectile. However, environmental and cultural factors, such as soil settlement, frost-heave action, and removal and dumping activities, can alter the burial depth. These factors are site dependent and must be considered when evaluating an area. If removal and dumping activities have been documented, then this information can be used to adjust the estimated penetration depths. If not, soil sampling may give some indication to such activities, however, it is likely that the penetration depth will differ

significantly from depth of burial. The natural processes that cause frost-heave generally work in favor of a UXO remediation, i.e., the frost-heave action moves material upward. Therefore, frost-heave does not negatively impact the penetration estimates obtained with UXO-PenDepth because the UXO still will be within the estimated depth. However, the penetration estimates may be excessive if frost-heave action has moved the UXO toward the surface.

The user of UXO-PenDepth must be conscientious in the selection of a munition for estimating penetration depth. There are numerous versions of a munition (e.g., 81mm M374 HE, 81mm M375 Smoke, 81m M301A2 Illumination, 81mm M880 SRTR Ttraining) and although the versions may be similar, the differences in geometry, weight, and other required input parameters may be great enough to significantly alter the penetration depth. Therefore, if the desired munition is not in the UXO-PenDepth database, care must be exercised when selecting a characteristic munition to ensure that the input parameters are similar so that the estimated penetration depths are representative of the desired munition.

3.0 PERFORMANCE OBJECTIVES

The objective is to provide realistic depth of penetration estimates for munitions using a physics-based algorithm within the software UXO-PenDepth. The physical dimensions and weight of the munitions, and type of filler material, weight and distribution within the munitions are required to generate an input model. Also required are the minimum and maximum impact velocities and impact angles, and a subsurface soil model that describes the soil type (sand, silt, clay), layer thickness, and soil resistance parameter. The input data are used to estimate the depth of penetration, which are summarized in a depth penetration range plot. The estimated penetration depths from UXO-PenDepth are compared to actual recovery data available from the National Defense Center for Energy and Environment (NDCEE) database, and data provided by Cliff Youmann, Montana Army National Guard, acquired during SERDP/ESTCP projects. The majority of the recovered UXO are within the UXO-PenDepth minimum firing parameter estimate, although the majority of the recovery depths for a given UXO category are shallower than the shallowest UXO-PenDepth penetration estimate (except for the 60 mm and 81 mm). The difference between the field recovery data and the theoretical estimates may be attributed to factors such as: 1) the modeled UXO in this study are not representative of the recovery data, 2) differences in subsurface soil structure and soil parameters, 3) variations in firing parameters and methods of firing, and 4) UXO movement after initial penetration and prior to recovery. The performance objectives are summarized in Table 2.

4.0 SITE DESCRIPTION

This project did not involve a field demonstration, therefore no site description is included.

Table 2. Performance objectives.

Performance Objective	Metric	Data Required	Success Criteria	Results
Obtain realistic ordnance depth of penetration estimates using a physics-based algorithm within the software UXO-PenDepth	Depth of penetration	Physical specifications and firing parameters of ordnance; layered earth model with soil type (sand, silt, clay), thickness and soil resistance parameter specified	Recovery results shallower or within bounds of the UXO-PenDepth penetration estimates	The majority of the recovered UXO are within the UXO-PenDepth minimum firing parameter estimate, although the majority of the recovery depths for a given UXO category are shallower than the shallowest UXO-PenDepth penetration estimate (except for the 60 mm and 81 mm)

5.0 TEST DESIGN

The penetration of seven ordnance, ranging in size from 40 mm to 155 mm (Fig. 5), were studied. The ordnance represent those in the Aberdeen Proving Ground (APG) Standard UXO set. An ordnance input file was created for each munitions used. These files contain a digitized form of the projectile and other technical information (detailed dimensions, weight, nose type, etc.) required by the program code. These files are available for selection from the ordnance database.

Figure 5. The seven munitions used in the depth of penetration study.

5.1 MODEL SCENARIOS

An UXO-PenDepth simulation is executed for each ordnance using a suite of soil resistance parameters which represent different soil types and moisture conditions. The simulations represent a half-space and two-layer subsurface soil structure. The suite of soil types is based on the Unified Soil Classification System (USCS), which uses gradation and plasticity characteristics to define a soil type. This system was chosen because the system used to differentiate the soil resistance parameter SNUM describes the soils using generalized material properties. Under the USCS, a sand is defined as a soil with ≥ 50% retained on the No. 200 (0.075 mm) sieve, and ≥ 50% passing the No. 4 (4.75 mm) sieve. Fine-grained soils (silt or clay) are defined by ≥ 50% passing the No. 200 sieve. A silt and clay are differentiated by their plasticity characteristics (plasticity index and liquid limit). The soil types studied include sand, silt, and clay. For each of the three soil types, moisture states representing dry, moist, and wet conditions were evaluated. A dry soil is considered to have less than 10 percent water content, whereas a moist soil has a water content between 10 and 30 percent, and a wet soil greater than 30 percent. A combination of soil type and moisture content is represented by the appropriate soil resistance parameter SNUM (Table 1) in UXO-PenDepth. The matrix of SNUM values selected for this study is given in Table 3.

Table 3. Values of the soil resistance parameter
SNUM used to represent the various soil scenarios.

Soil Resistance Parameter SNUM for Soil Scenarios			
	Sand	**Silt**	**Clay**
Dry	6	5.5	5
Moist	7	8	9
Wet	8.5	10	12

Penetration scenarios include homogeneous half-space models using the layer parameters given in Table 3 for the seven ordnance under both minimum and maximum firing conditions (referred to subsequently as minimum and maximum impact parameters). Two-layer scenarios include sand-silt, sand-clay, silt-sand, silt-clay, clay-sand and clay-silt models using combinations of the SNUM values listed in Table 3. First layer thickness values used were 0.1/0.2 m, 0.4 m. 0.6 m and 1 m. For the larger ordnance (105 mm and 155 m), first layer thickness ranged from 1 to 5 m.

5.2 MUNITIONS FIRING PARAMETERS

Prior to modeling the penetration depth, it was necessary to obtain input parameters for the impact velocity and impact angle of each ordnance. Since these values are generally unknown, it was decided to use values for the terminal velocity and angle of fall to represent the impact velocity and impact angle, respectively. As with the drawing specifications, information regarding ordnance firing parameters is not readily available. It was necessary to request the Firing Tables and Ballistics Division, Aberdeen Proving Ground, to use the program G-traj to calculate the terminal velocity and angle of fall for each ordnance at different charge levels and quadrant elevations (angle between the horizontal plane and axis of the firing tube). To minimize the amount of data, only the terminal velocity and angle of fall at the minimum and maximum

charge levels were used. The minimum and maximum firing parameters provide a lower and upper bound on the depth of penetration. A summary of firing parameters for the munitions used is given in Table 4.

Table 4. Firing parameter values used to approximate the impact velocity (terminal velocity) and impact angle (angle of fall).

		Minimum		Maximum	
Ordnance	**Muzzle Velocity (m/s) (min./max.)**	**Terminal Velocity (m/s)**	**Angle of Fall (deg)**	**Terminal Velocity (m/s)**	**Angle of Fall (deg)**
40 mm MK2	853.4	216.7	49.67	263.4	78.53
57 mm APC M86	823.0	223.0	34.76	274.3	78.98
60 mm M49A3	52/166	49.3	46.41	127.3	81.56
81 mm M374A3	66/267	63.6	45.96	200.3	81.51
105 mm M60	199.5/482.2	175.0	42.64	311.9	72.96
105 mm M456	1,173.5	155.5	68.85	177.4	85.61
155 mm M483A1	297/676	238.6	44.78	347.0	75.26

5.3 UXO-PenDepth DESCRIPTION

The UXO-PenDepth software has a windows-based graphical user interface (GUI) (Fig. 6). The user creates a soil layer model (number of layers, thickness, SNUM), selects an ordnance from the database, and inputs the impact velocity and impact angle. At this point, the user chooses to either “Run Penetration” to obtain a plot of the projectile penetration path (depth at different times) (Fig. 7a), or “Run UXO” to view the depth penetration range (DPR) plot (Fig. 7b). The DPR represents the results of hundreds or thousands of penetration simulations (like that shown in Fig. 7a) presented in a single plot. The DPR plot exhibits curves of constant penetration depth for multiple combinations of impact velocity and impact angle. The range of impact velocity and impact angle can be specified by the user to simulate realistic range conditions and ordnance-specific considerations. In this study, the depth of penetration is measured to the center of gravity (CG) of the ordnance.

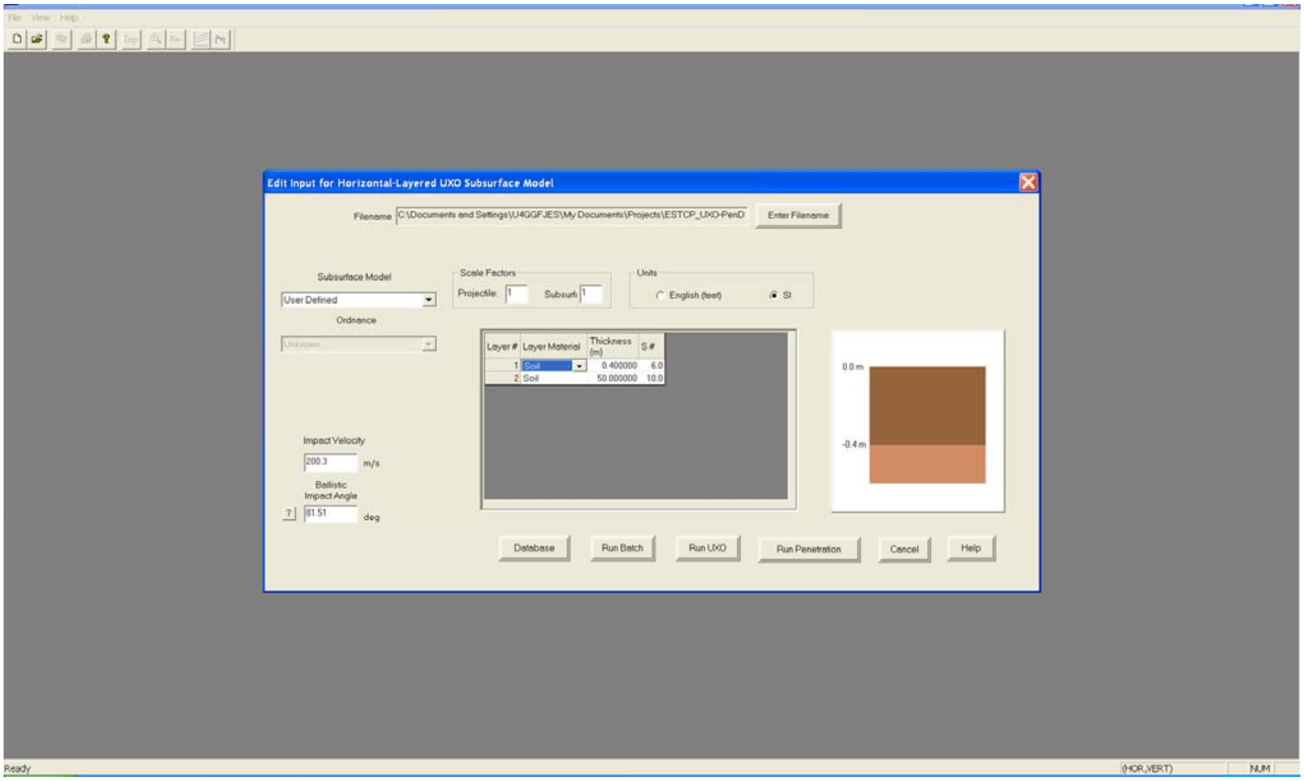


Figure 6. UXO-PenDepth GUI.

6.0 DATA ANALYSIS AND PRODUCTS

The discussion below describes the UXO-PenDepth penetration analyses and penetration summary for the seven munitions studied.

6.1 UXO-PenDepth RESULTS

The model results presented below represent the UXO-PenDepth simulations for both a half-space and 2-layer earth based on the soil matrix in Table 3. Because the general penetration behavior is similar for all the munitions studied, only the results for the 81 mm are presented in this section. The DPR plots for the other munitions are provided in Appendices B and C.

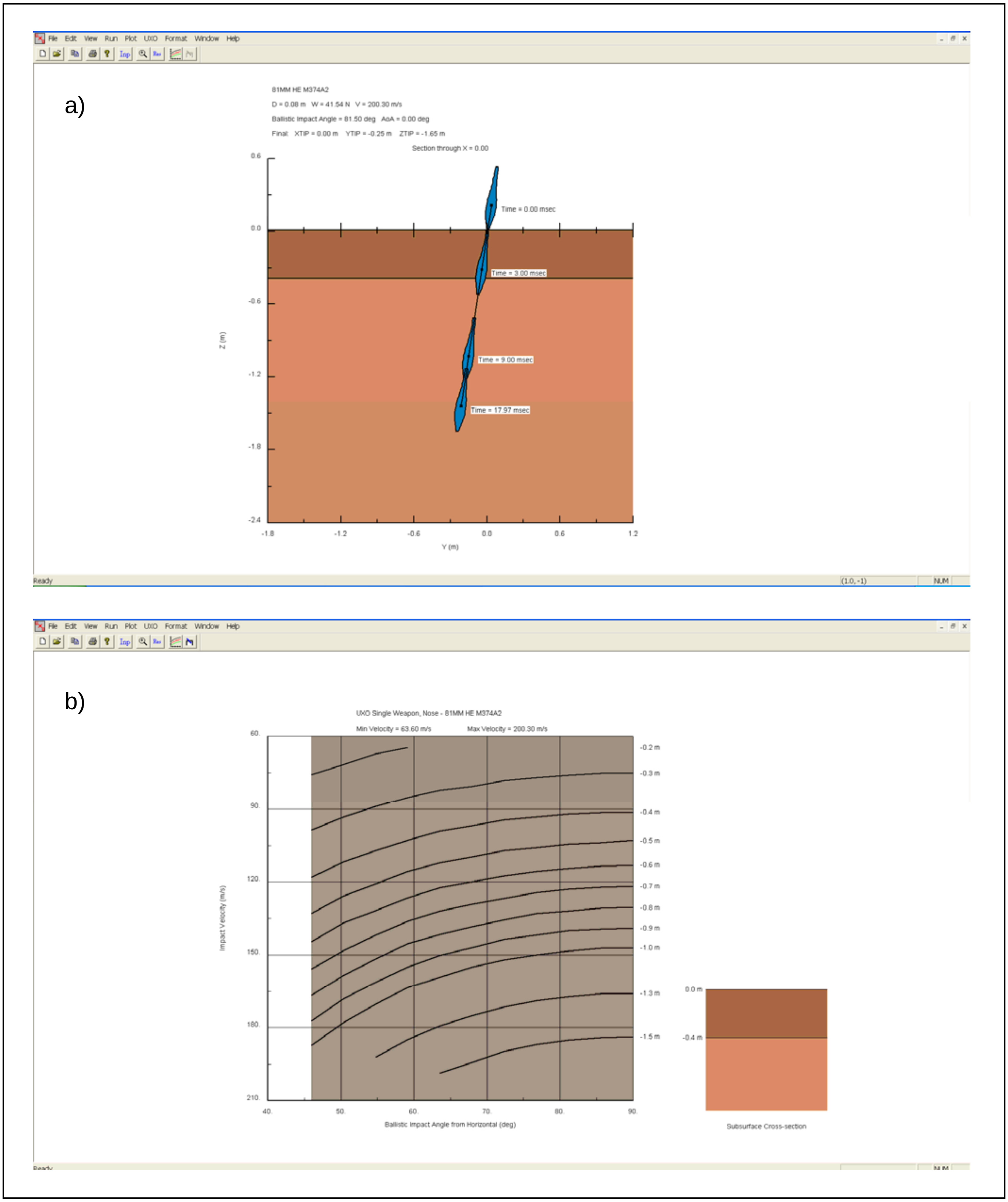


Figure 7. Output from UXO-PenDepth when a) Run Penetration and b) Run UXO are selected.

6.1.1 HALF-SPACE SCENARIOS

The DPR plots for a sand, silt, and clay half-space under dry, moderate, and wet moisture conditions for the 81-mm mortar are given in Fig. 8. These plots clearly show how an increase in soil moisture reduces the soil resistance and greater penetration is achieved. A plot (Fig. 9) of the three moisture states together for the sand, silt, and clay half-spaces at up to 0.6-m penetration shows that as the soil resistance decreases (SNUM increases), a lower impact velocity and impact angle can result in the same depth of penetration. These plots emphasize the significance the soil resistance parameter has in determining depth of penetration.

The depth of penetration in a sand, silt, and clay half-space for the various ordnance is summarized in Figs. 10 and 11. Figure 10 is penetration depth achieved using the minimum impact parameters (velocity and angle), whereas Figure 11 was constructed from data generated using the maximum impact parameters. The plot (a) in each figure shows data for the seven ordnance, while plot (b) only shows those munitions 81-mm and smaller plus the 105-mm HEAT. The symbols on the curves represent the SNUM associated with the dry and wet moisture states to aid in visualizing the limits of the individual curves. Note that some points on the 60-mm and 81-mm munitions curves in Fig. 10 do not plot below 0-m penetration depth. Using the minimum firing parameters, the CG of the 60 mm does not penetrate the earth under all moisture states for the three soil types, and the CG of the 81 mm does not penetrate the earth under dry moisture conditions. Using the maximum firing parameters, the CG of all of the seven munitions for all soil scenarios penetrates the surface. For the sand, silt, and clay half-spaces with SNUM 5 to 12 (dry to wet moisture states) and ordnance size 81-mm and smaller plus the 105-mm HEAT, the depth of penetration achieved using minimum impact parameters is < 1 m (Fig. 10b); penetration depths achieved using maximum impact parameters is < 2.4 m (Fig. 11b).

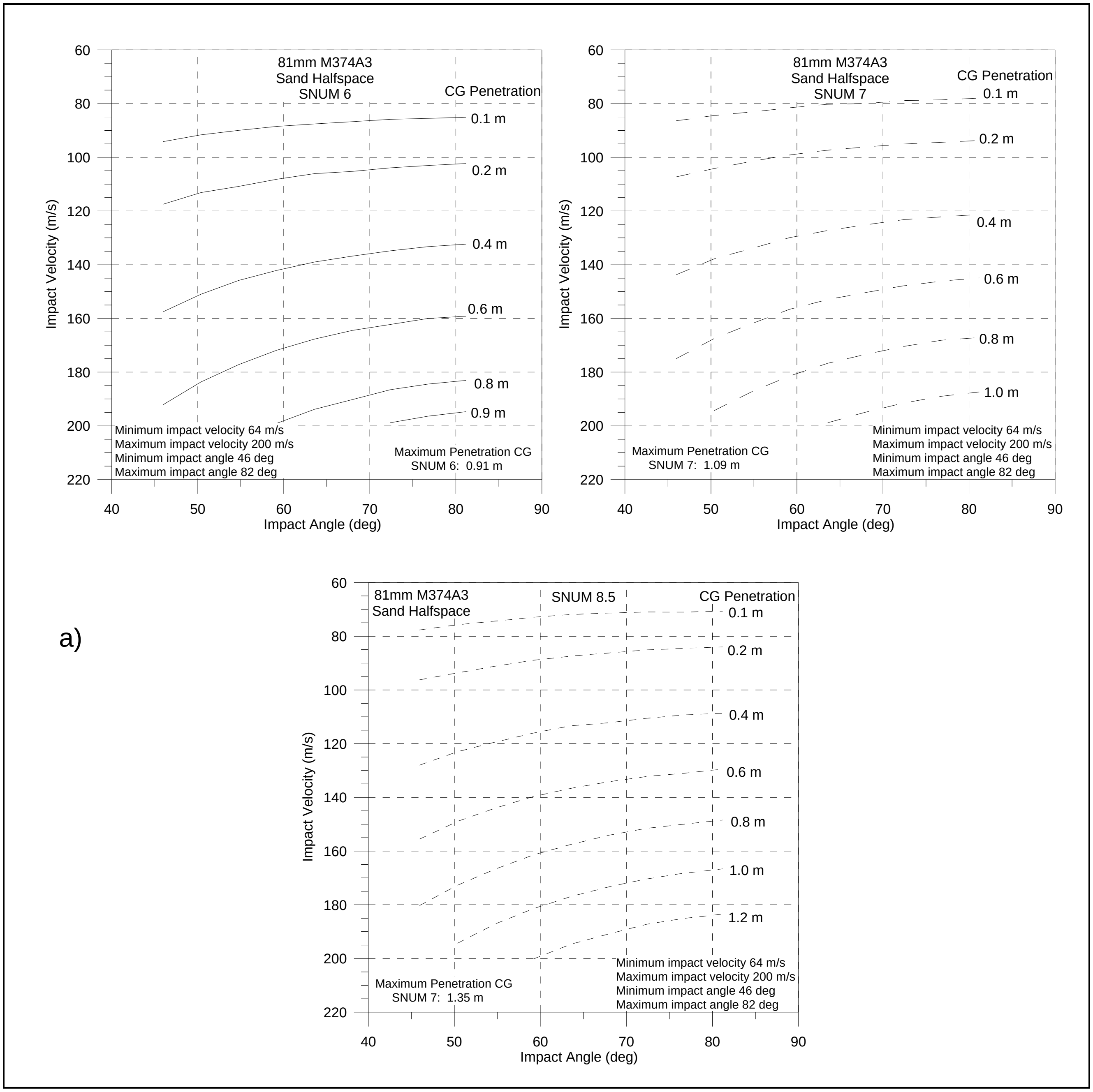


Figure 8. 81 mm DPR plots for sand (a), silt (b), and clay (c) under dry (solid curves), moderate (medium dashed curves), and wet (small dashed curves) moisture conditions.

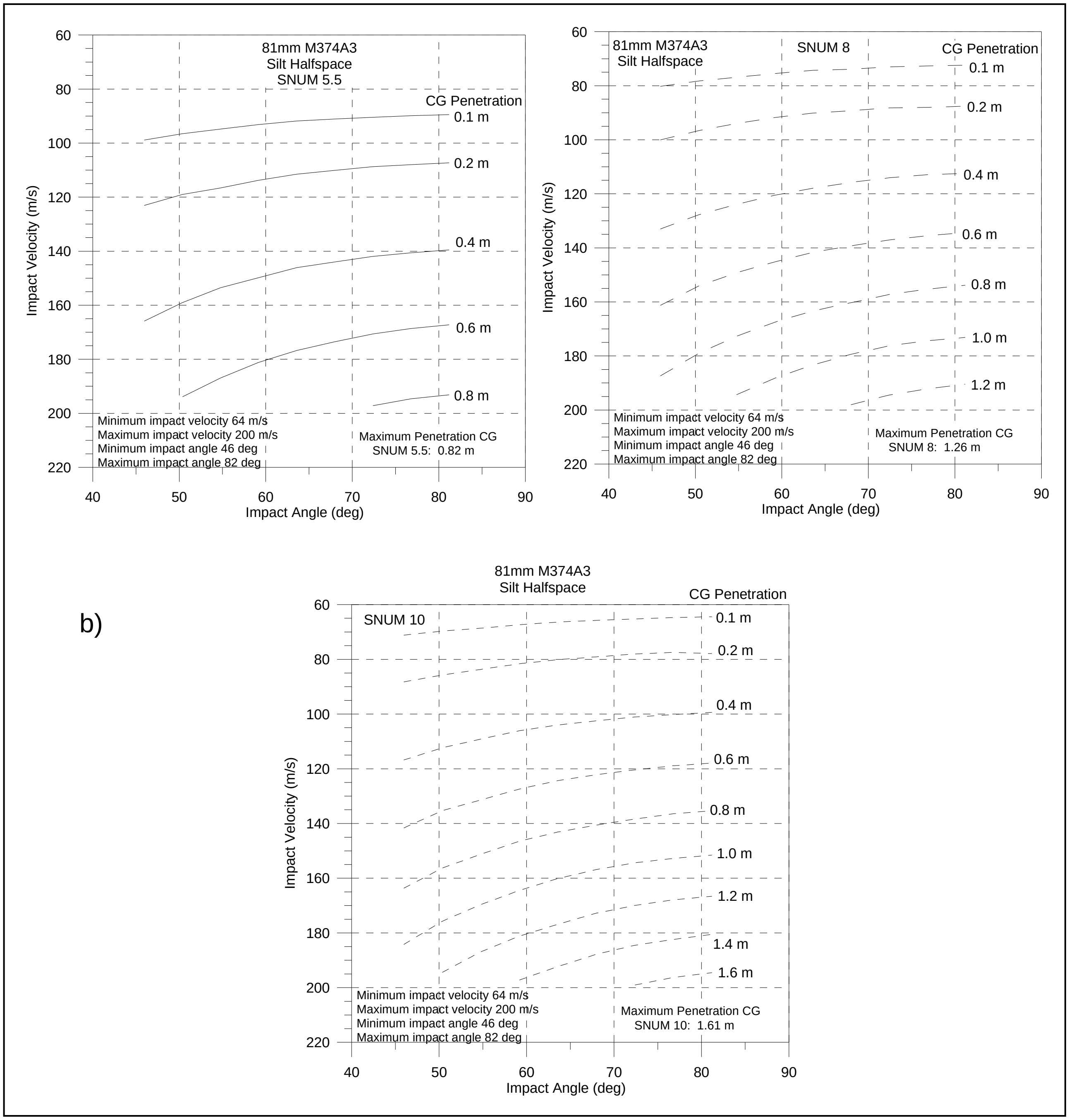


Figure 8. Continued.

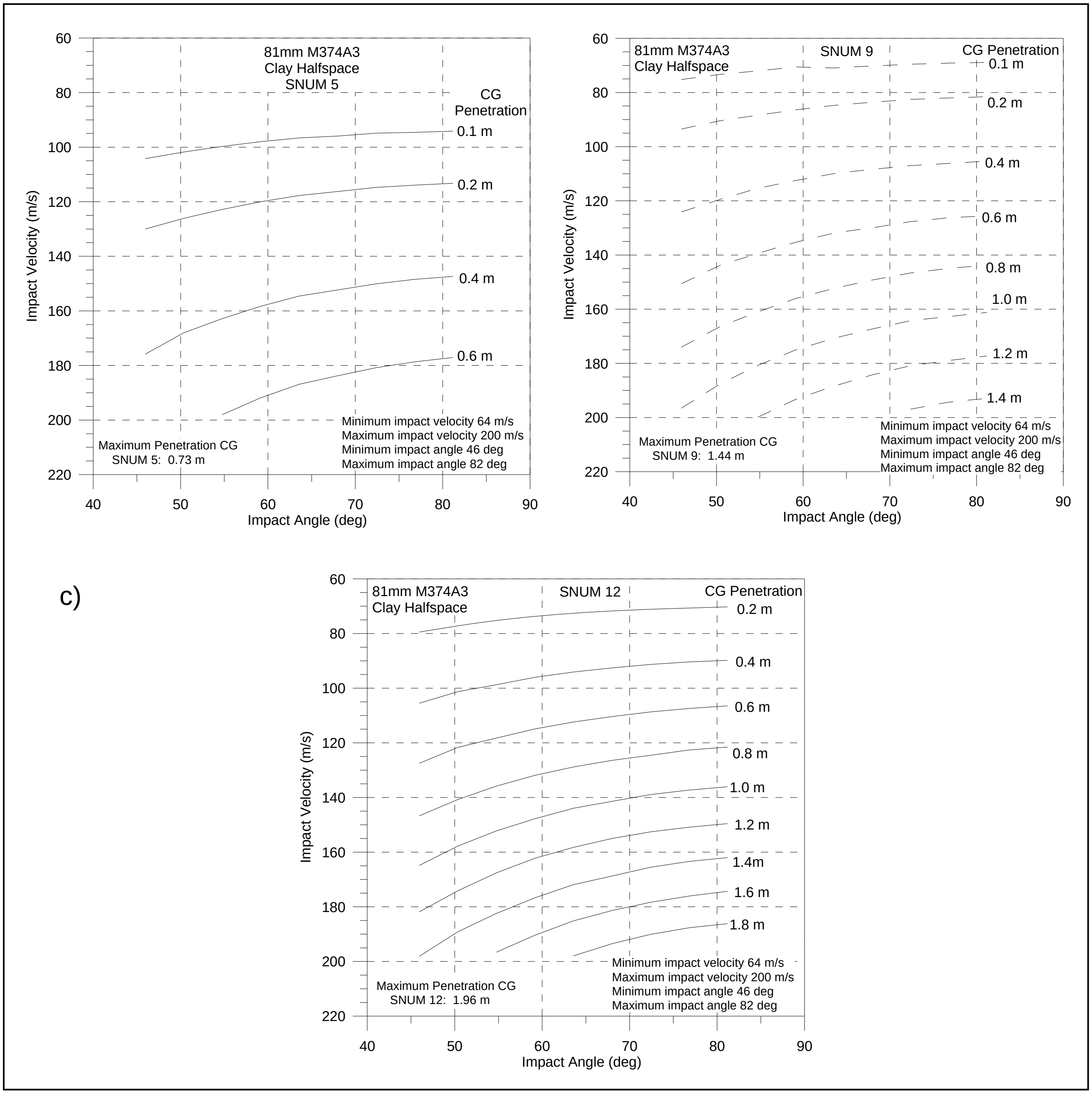


Figure 8. Concluded.

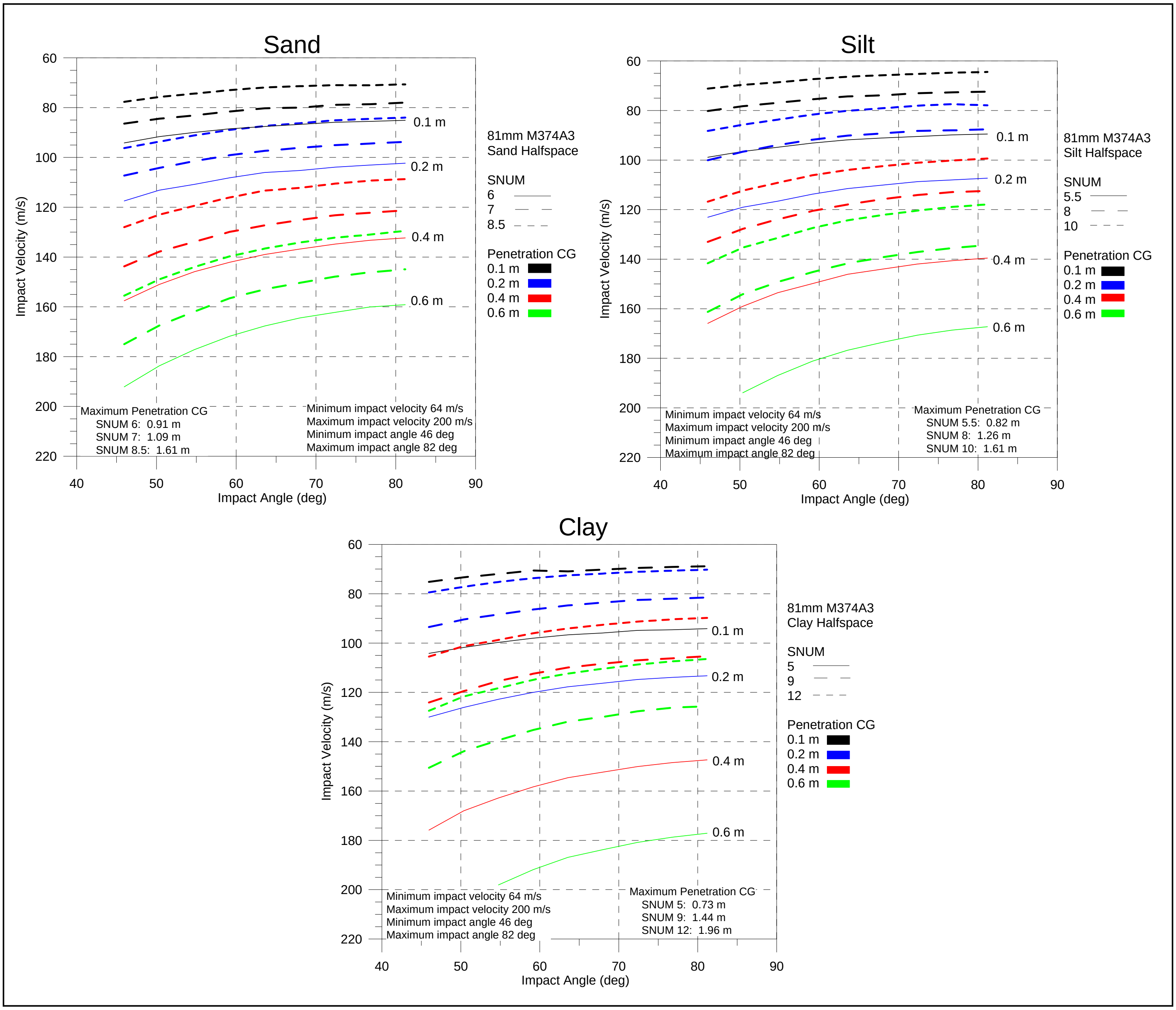


Figure 9. 81-mm depth penetration range plots for soil half-space of sand, silt and clay.

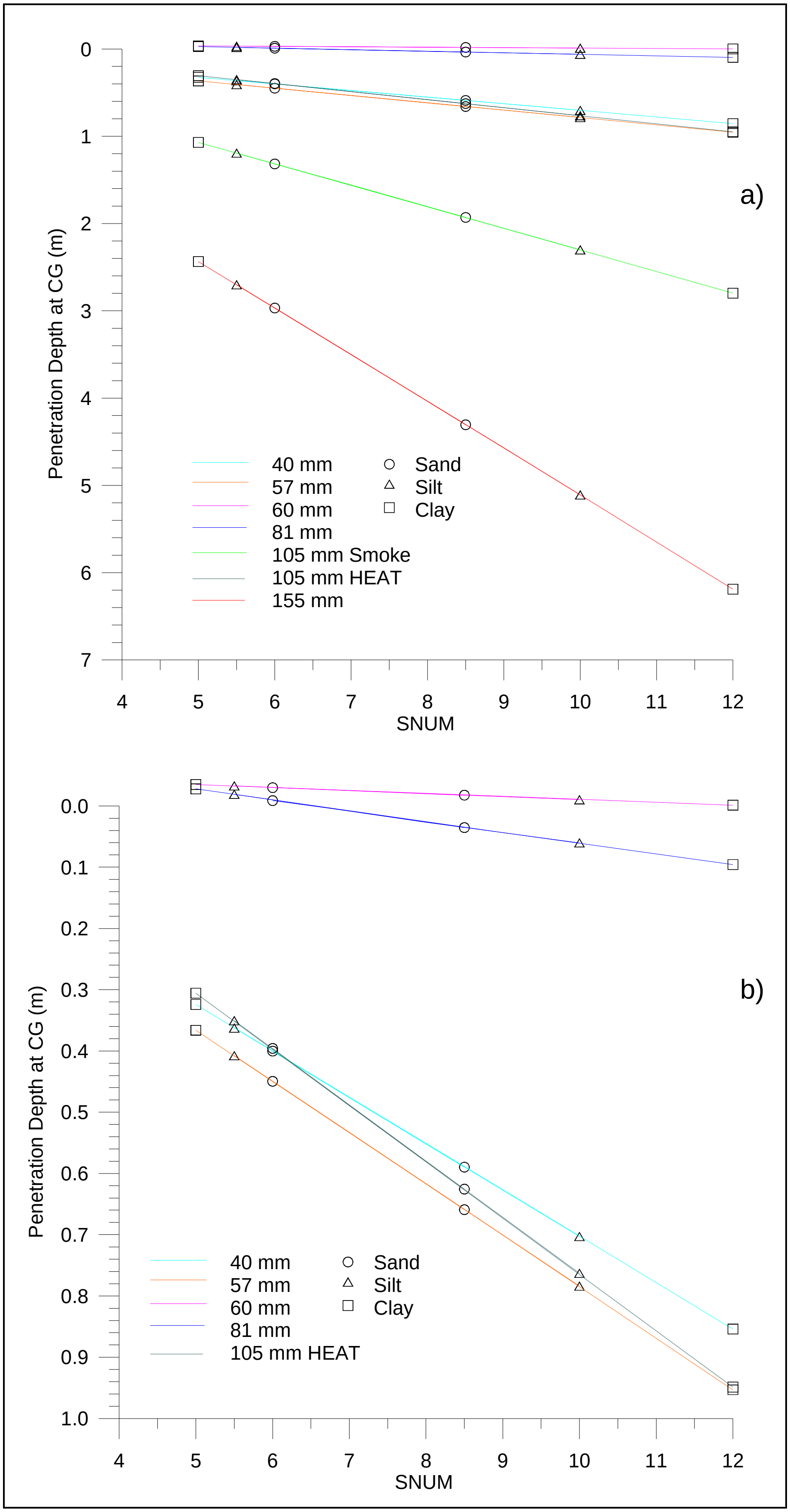
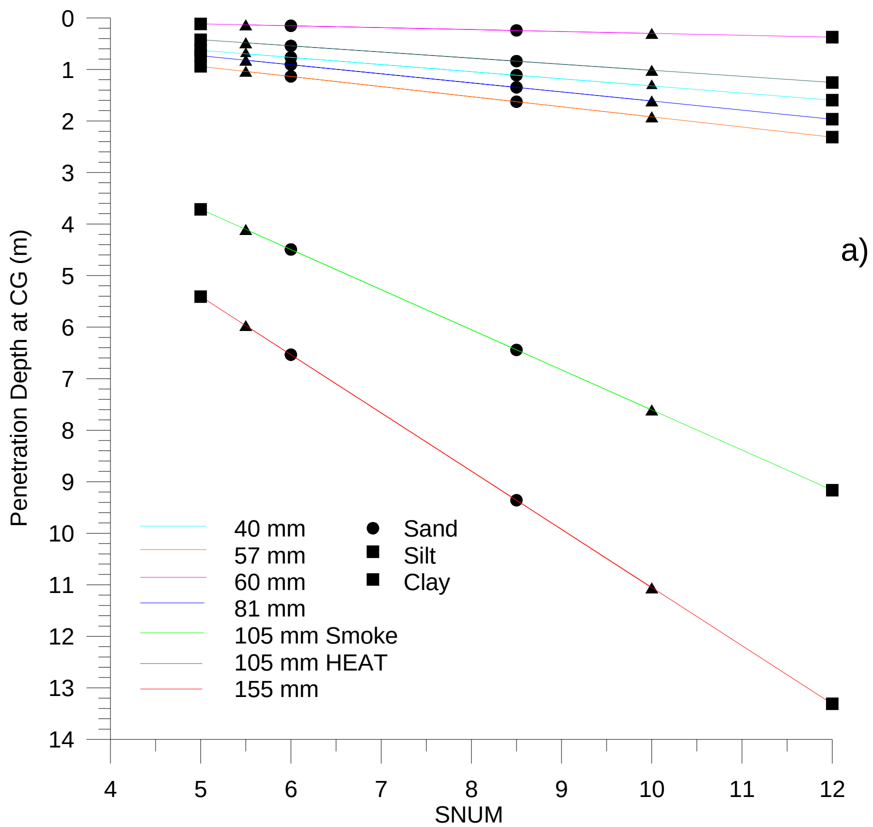


Figure 10. Depth of penetration (half-space) obtained using minimum impact parameters (velocity and angle) for seven ordnance (a) and those 81-mm and smaller plus the 105-mm HEAT (b).



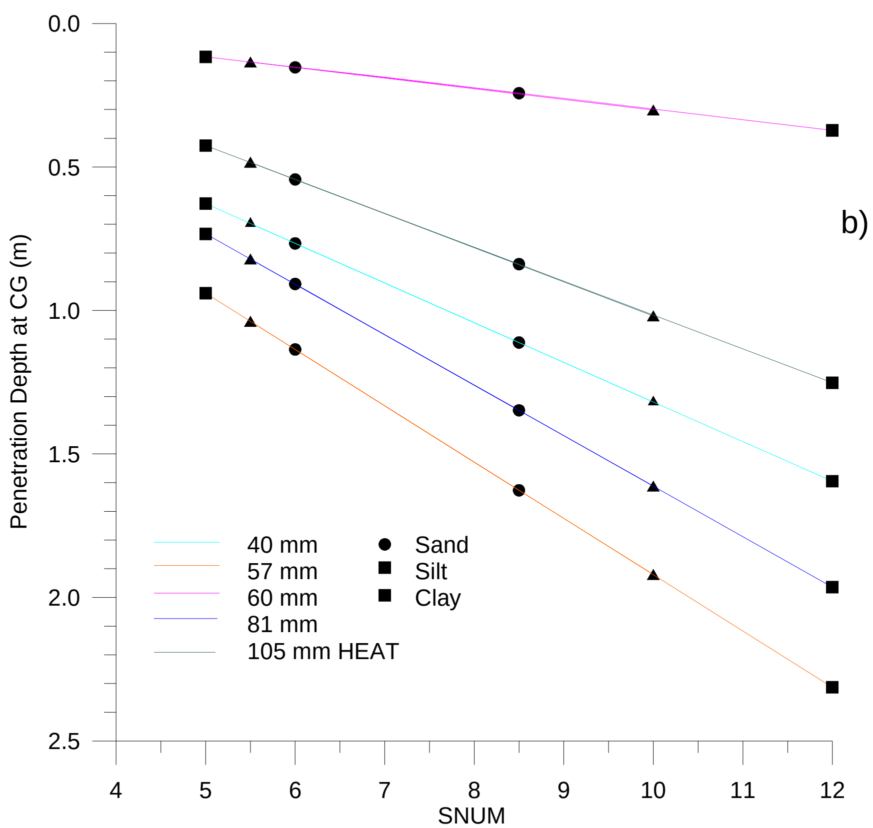


Figure 11. Depth of penetration (half-space) obtained using maximum impact parameters (velocity and angle) for seven ordnance (a) and those 81-mm and smaller plus the 105-mm HEAT (b).

6.1.2 2-LAYER MODEL SCENARIOS

Two general observations were noted for the two-layer soil models. Firstly, depth of penetration increases as first-layer thickness increases when the soil resistance of the first layer is less than the soil resistance of the second layer ($SNUM_1 > SNUM_2$), and penetration depth is less than or equal to the half-space penetration depth. Secondly, depth of penetration decreases as first-layer thickness increases when soil resistance of the first layer is greater than the second layer soil resistance ($SNUM_1 < SNUM_2$), and penetration depth is greater than the half-space penetration depth. This behavior is illustrated in Fig. 12 for the 57 mm. The layer models are a silt-sand and silt-clay, with the silt layer at a moderate (SNUM 8) moisture state. The behavior switches from the first observation to the second at the half-space penetration depth (marked by a cross and "×" on Fig. 12). The curves with open symbols represent minimum impact conditions, whereas the solid symbol curves are for maximum impact conditions.

An example of the penetration data generated for the seven ordnance under minimum and maximum impact conditions is presented in the next set of plots (Fig. 13). The soil models are a sand-silt and sand-clay having dry, moderate and wet moisture contents. First-layer thicknesses are 0.1/0.2, 0.4, 0.6 and 1 m. The data were generated for an 81-mm mortar. The 81 mm has a low minimum impact velocity (64 m/s) so only a first-layer thickness of 0.1 m was used when generating the penetration depths with the minimum impact parameters. The mortar does not penetrate into the subsurface its entire length under minimum impact conditions, although the CG does penetrate the surface under moderate and wet moisture states. The plots in Fig. 13 exhibit characteristics that have been shown previously. For example, as was seen in the trajectory study, the effect of reducing the soil resistance (increasing SNUM) lengthens the travel path of the ordnance. Also, as the moisture content of the soil increases, the depth of penetration increases. Note that when penetration has exceeded that which would be achieved for the first-layer half-space (blue "×" on plots in Figs. 13a-c), the separation between curves (curves with solid symbols that represent maximum impact parameter conditions) having different first-layer thickness decreases as the soil resistance of the first-layer decreases (SNUM and moisture content increase) (Figs. 13a-c). This reflects the fact that the SNUM for the top sand layer is approaching the SNUM of the lower silt or clay layer. Figure 13d combines information from Figs. 13a-c to compare the three moisture states for a first-layer thickness of 0.1, 0.2, and 0.6 m. Again, the plot emphasizes the influence of the layer properties the ordnance is currently penetrating has on the depth of penetration.

A depth penetration range plot for the 81-mm sand-silt scenario in Fig. 13 is given in Fig. 14. The sand has a thickness of 0.6 m and moderate moisture state (SNUM 7). Depth of penetration to the nose tip is shown in Fig. 14a. Penetration is identical for the three moisture states of the silt layer up to a penetration depth of 0.6 m because the mortar has not yet entered the silt. At depths greater than 0.6 m, penetration into the silt occurs and influence of the silt layer increases (separation of the curves at a given penetration depth) as the mortar penetrates deeper. Figure 14b shows the DPR plot for penetration measured to the CG. When the CG reaches a depth of 0.5 m, the nose has already penetrated into the silt layer. Thus, separation of the curves for the three SNUMs is observed at this depth and beyond. For comparison, Fig. 14c represents the DPR at the nose tip for an 81 mm into a sand half-space (SNUM 7). Note that the solid curves are identical to those in Fig. 14a (penetration at nose tip) up to 0.6 m, the thickness

of the sand. Below that depth, the solid curves in the 2-layer scenario (Fig. 14a) for a dry silt (SNUM 5.5) are shifted down because of a greater soil resistance than the sand, whereas the dashed curves are shifted up because of a higher SNUM (lower soil resistance) of the silt layer.

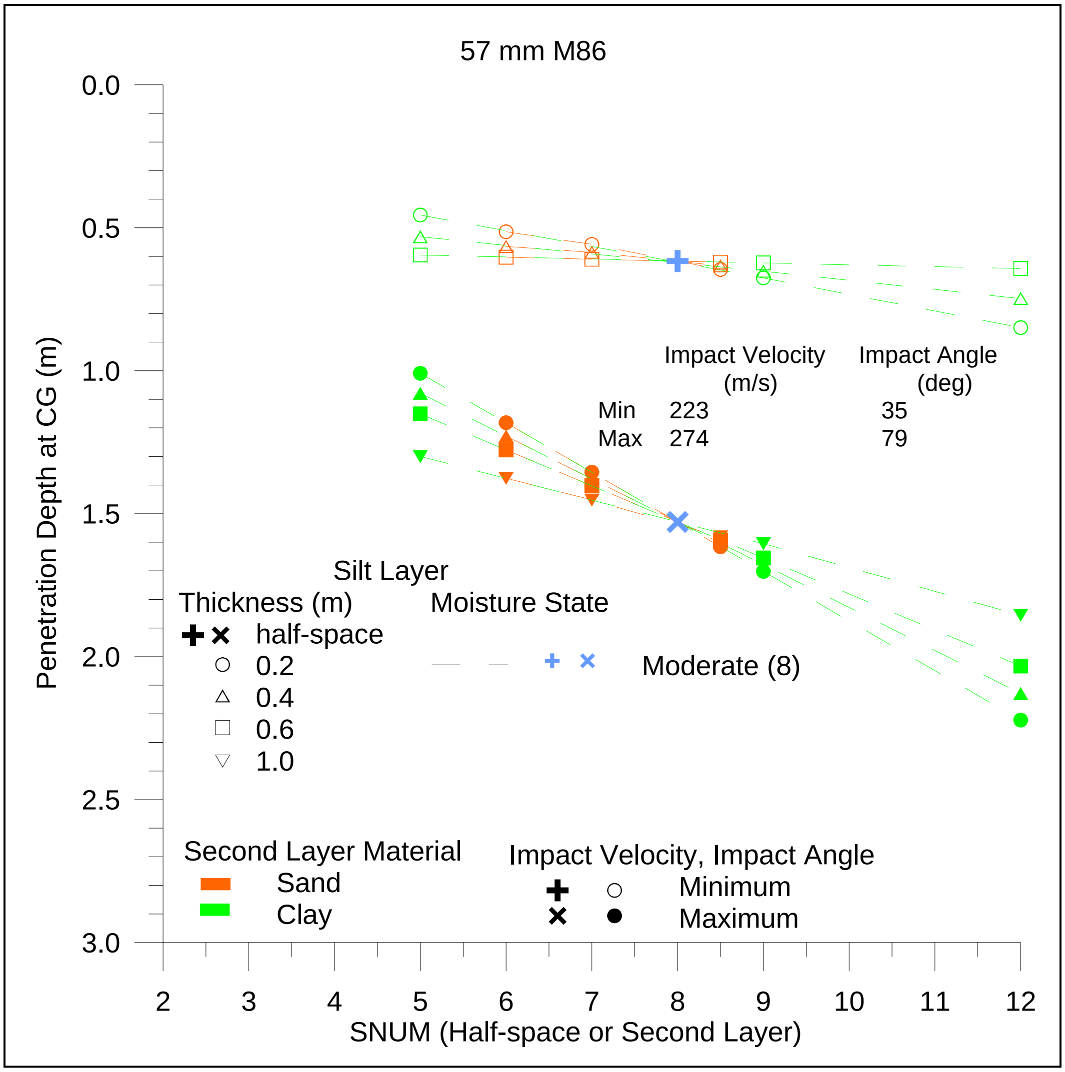


Figure 12. Depth of penetration for a 57 mm into a 2-layer silt-sand and silt-clay soil structure. Open symbols represent minimum impact parameters; closed symbols represent maximum impact parameters. The silt has a moderate (SNUM 8) moisture state. The blue cross and "×" represent penetration depth for a silt half-space at minimum and maximum impact parameters, respectively.

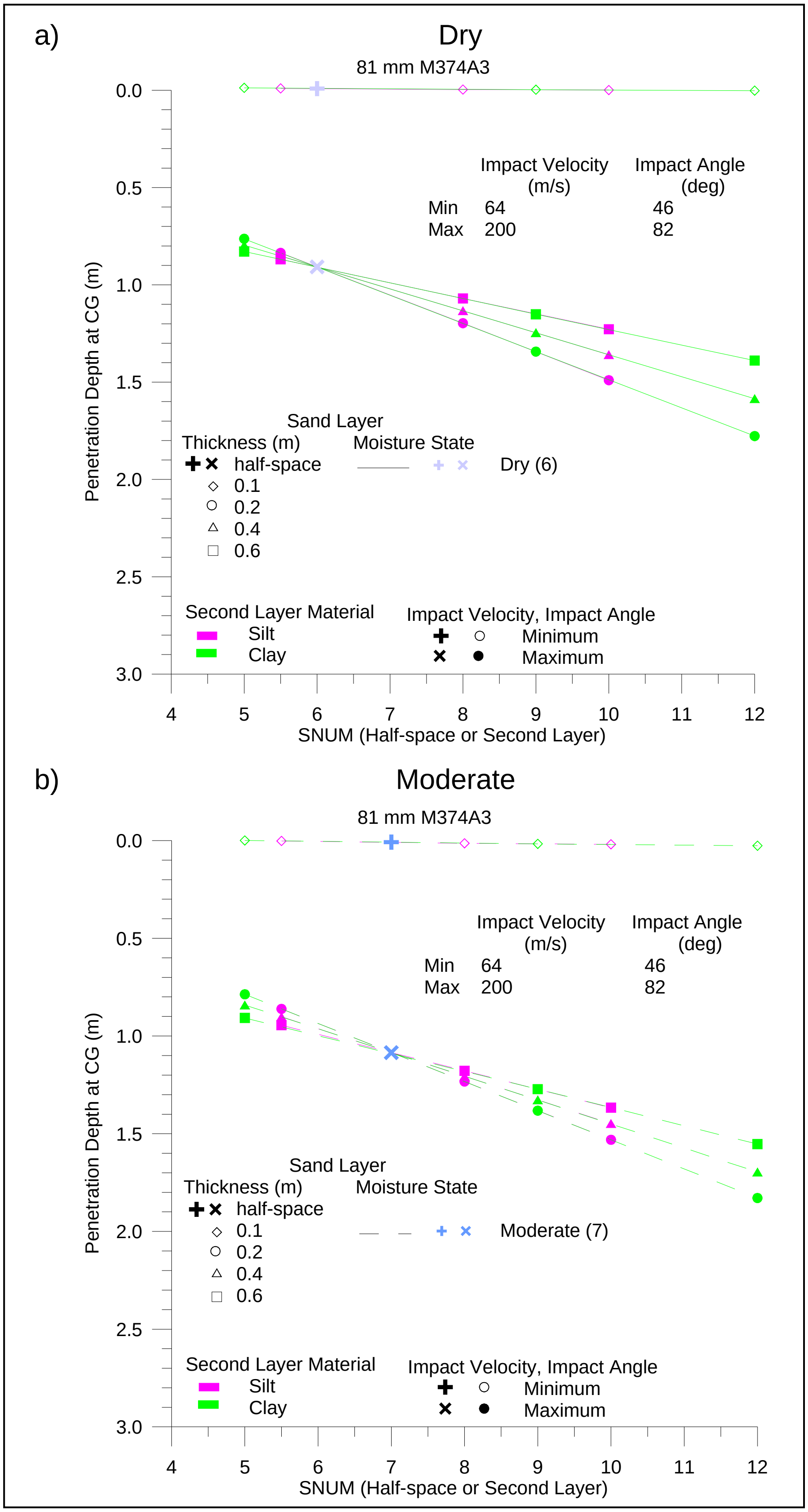


Figure 13. Depth of penetration plots for sand-silt and sand-clay soil models under dry (a), moderate (b) and wet (c) moisture conditions. (d) Comparison of the different moisture states at different first layer thicknesses h.

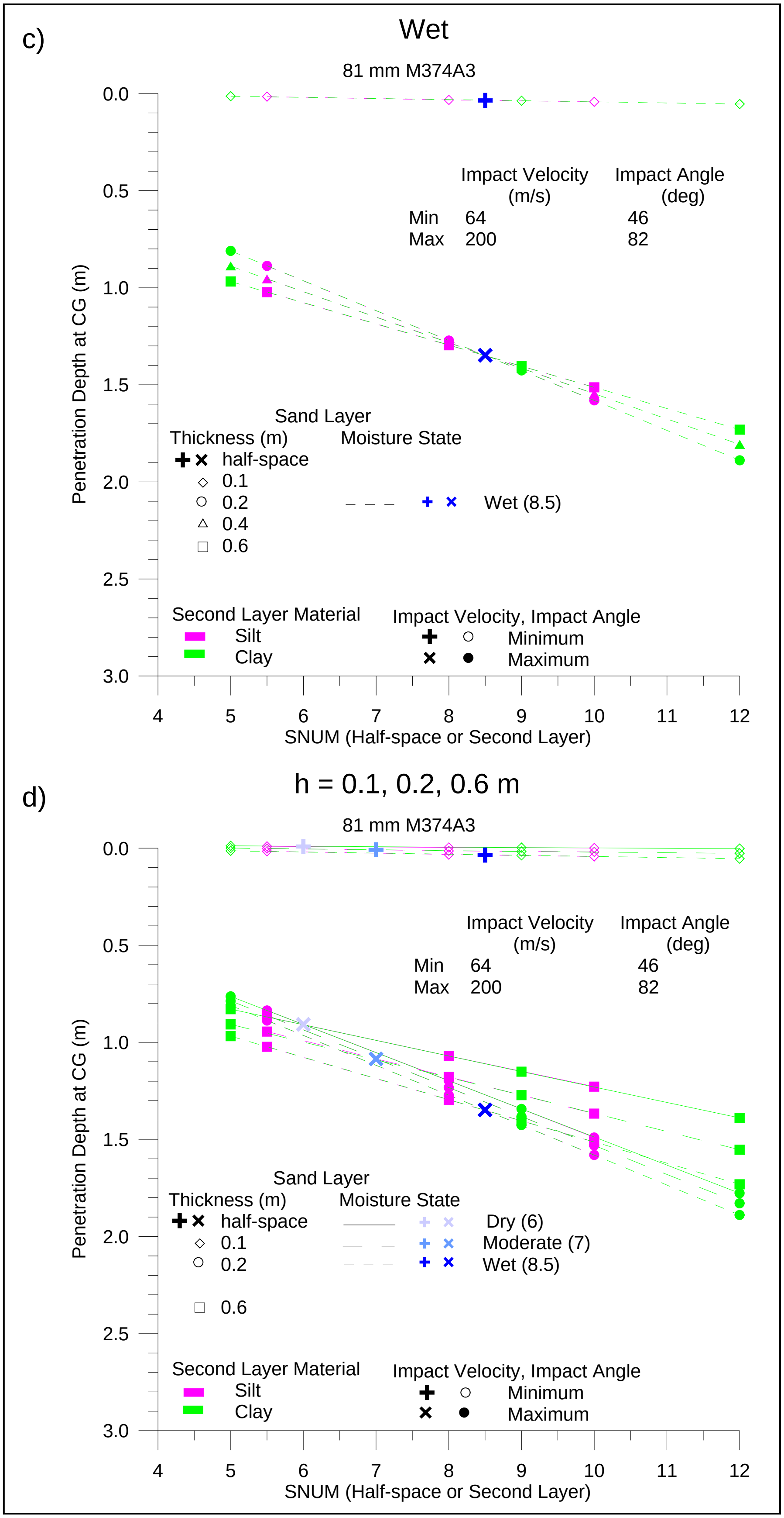


Figure 13. Concluded.

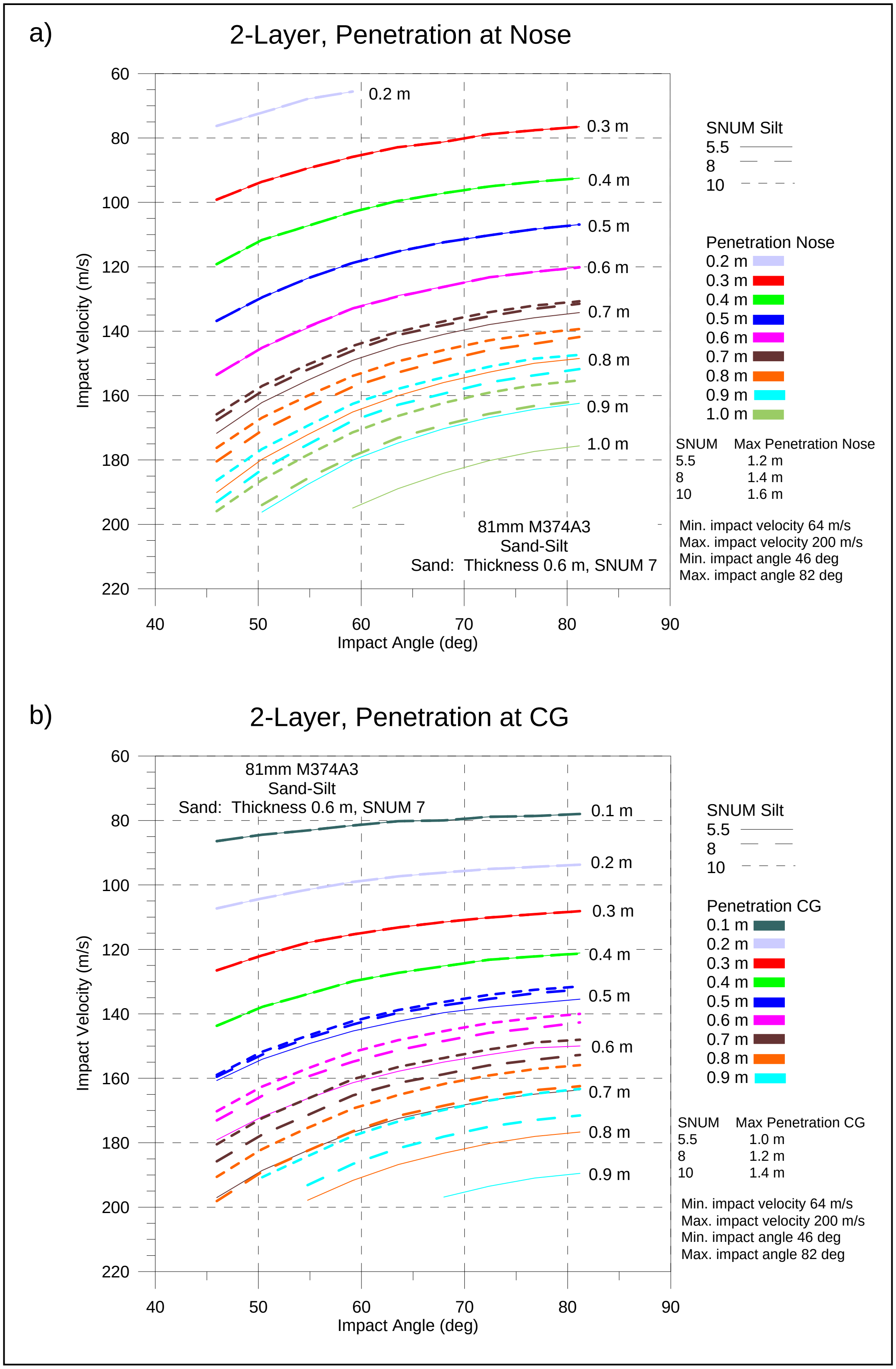


Figure 14. Depth penetration range plot for 81 mm into sand-silt (scenario in Fig. 13). Sand thickness is 0.6 m with moderate moisture content (SNUM 7). a) Penetration at nose tip; b) penetration at CG; c) penetration into a sand half-space (SNUM 7) for comparison.

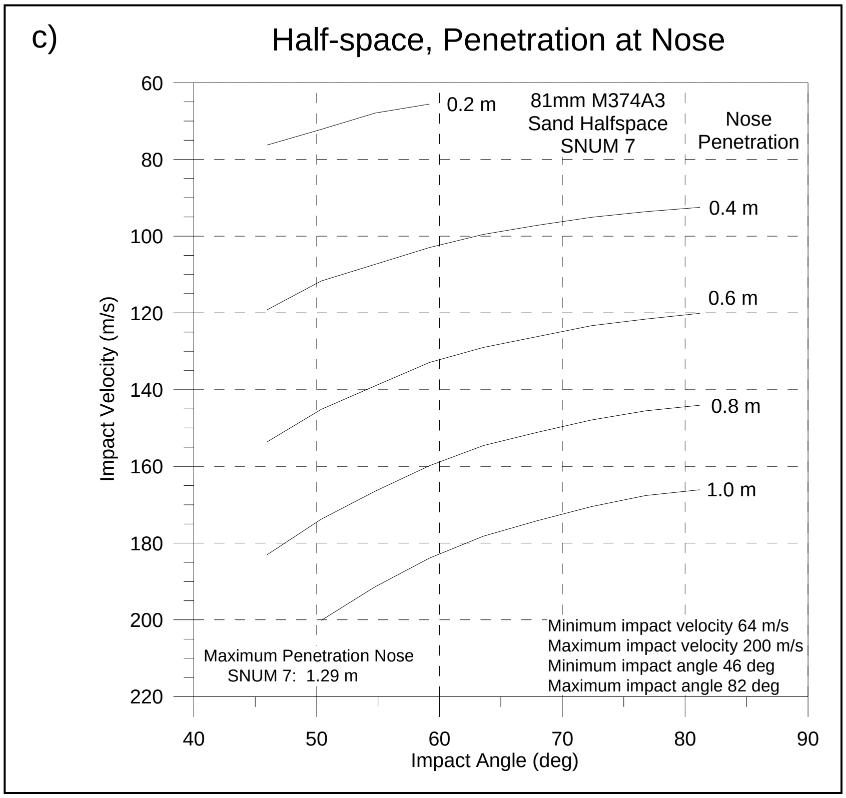


Figure 14. Concluded.

6.2 DATA PRODUCTS

The data products are the DPR plots for each of the seven ordnance undergoing penetration into the nine half-space soil scenarios, and 126 2-layer soil scenarios derived from the soil and moisture combinations in Table 3. The 2-layer scenario plots have been limited to a single first-layer thickness. If plots were constructed using all specified first-layer thickness combinations, there would be an overwhelming 406 plots. The DPR plots for the half-space scenarios are compiled in Appendix B; those for the 2-layer scenarios are compiled in Appendix C. An example of a DPR plot for the 60 mm penetrating a wet silt (SNUM 10) half-space and a silt-sand 2-layer model are shown in Fig. 15. The 2-layer model is for a moderately wet silt (SNUM 8) having a thickness of 0.1 m, overlaying a sand. Recall that the separation in the curves for a penetration depth less than the first layer thickness in the 2-layer scenario (Fig. 15b) reflects the fact that the measurement point is at the CG, which is in the first layer, and the nose of the projectile has already penetrated the second layer. These plots provide a quick reference for estimating the penetration depth of an ordnance for a given set of firing parameters. A summary of the minimum and maximum penetration depths for the nine half-space scenarios is given in Table 5.

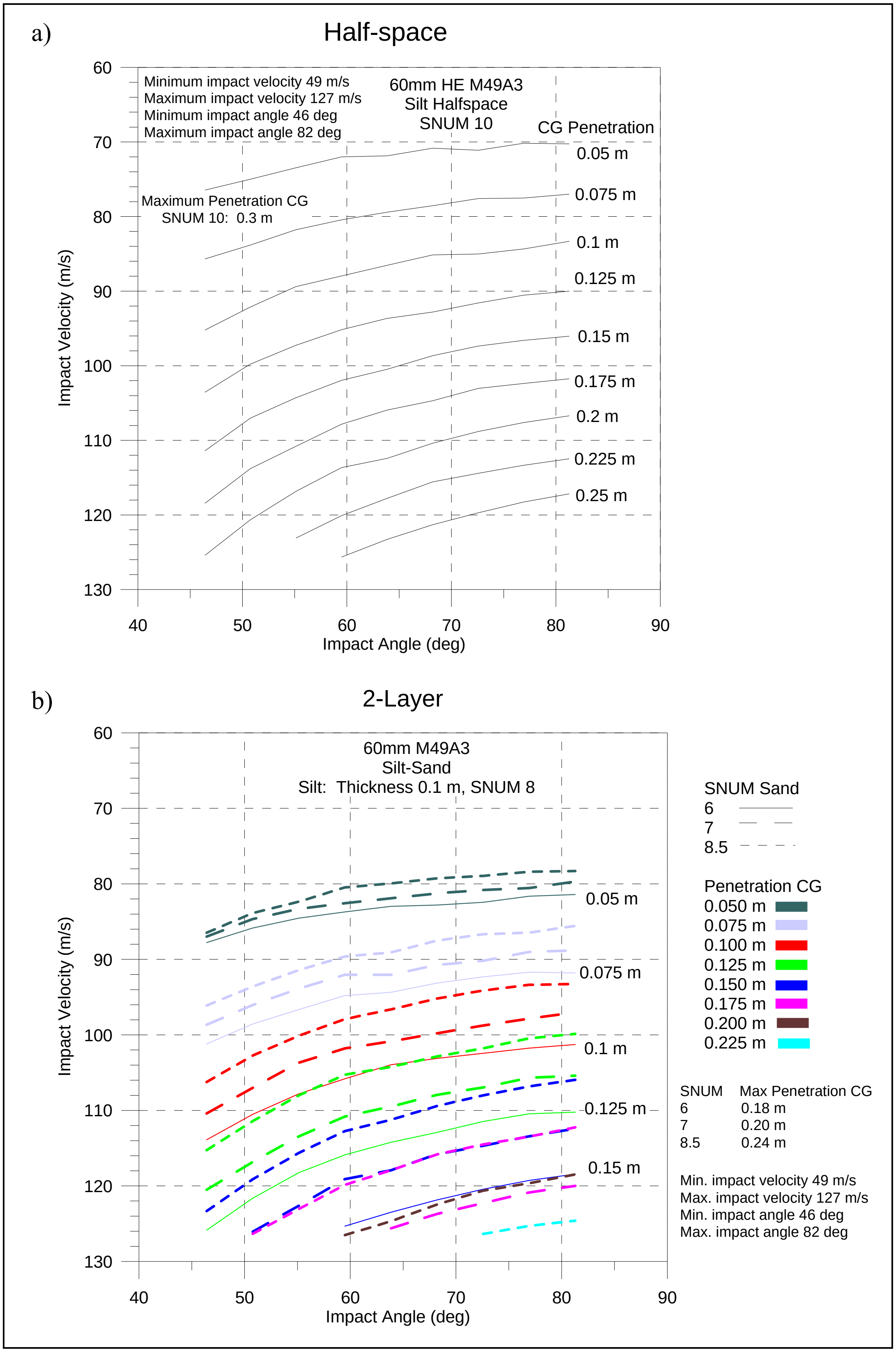


Figure 15. DPR plots for a 60mm HE M49A3. a) Half-space wet silt model and b) 2-layer moderately wet silt (thickness 0.1 m) overlaying a sand.

Table 5. Summary of minimum and maximum depth of penetration at CG for the seven ordnance and half-space soil scenarios.

		SNUM								
		Sand			Silt			Clay		
Ordnance	Half-space Penetration Depth at CG (m)	6	7	8.5	5.5	8	10	5	9	12
40 mm MK2	Minimim	0.40	0.48	0.59	0.36	0.55	0.70	0.32	0.63	0.85
	Maximum	0.77	0.90	1.11	0.70	1.04	1.32	0.63	1.18	1.60
57 mm APC M86	Minimim	0.45	0.53	0.66	0.41	0.62	0.78	0.37	0.70	0.95
	Maximum	1.14	1.33	1.63	1.04	1.53	1.92	0.94	1.72	2.31
60 mm M49A3	Minimum	--*	--	--	--	--	--	--	--	--
	Maximum	0.15	0.19	0.24	0.14	0.23	0.30	0.12	0.26	0.37
81 mm M374A3	Minimum	--	0.008	0.04	--	0.03	0.06	--	0.04	0.10
	Maximum	0.91	1.09	1.35	0.82	1.26	1.61	0.73	1.44	1.96
105 mm HEAT	Minimum	0.40	0.49	0.63	0.35	0.58	0.76	0.31	0.67	0.95
	Maximum	0.54	0.66	0.84	0.48	0.78	1.02	0.43	0.90	1.25
105 mm M60	Minimum	1.32	1.56	1.93	1.19	1.81	2.30	1.07	2.05	2.80
	Maximum	4.49	5.27	6.44	4.11	6.05	7.61	3.72	6.83	9.16
155 mm M483A1	Minimum	2.97	3.50	4.31	2.70	4.04	5.11	2.44	4.57	6.19
	Maximum	6.54	7.66	9.36	5.97	8.80	11.06	5.41	9.92	13.31

* No entry indicates that the CG did not penetrate the surface.

7.0 PERFORMANCE ASSESSMENT

7.1 COMPARISON WITH RECOVERY DATA

The performance of UXO-PenDepth is compared with available recovery data to assess if the depth of penetration estimates are reasonable. Recovery data were obtained from two sources, the NDCEE database and that provided by Cliff Youmans, Montana Army National Guard, from sites in Montana. The NDCEE recovery data are plotted in Fig. 16. These data represent all *fired* ordnance within their respective category, excluding fuzes, demolition material and clutter. Recovery depth in the NDCEE database represents the deepest depth that the UXO was recovered. Recovery information for the specific munitions studied in this report was not available, just information for the general ordnance category, i.e., 60 mm, 81 mm, etc. Table 6 summarizes the sites, ordnance listing, and total number of UXO recovered for each munitions size in Fig. 16. Soils information was only available for a small number of 60-mm and 81-mm munitions recovered, and those sites had a silt-sand-clay soil mixture. Note in Fig. 16 that the horizontal axes have the same scale, but the vertical axes differ. Only the 105 mm was recovered at depths greater than 1 m, and those were less than 1.22 m (48 in.). The majority of recovered ordnance reported in Fig. 16 are at a depth less than 51 cm (20 in.).

The recovery data from three sites in Montana are given in Table 7. The munitions recovered include 81 mm, 105 mm, and 155 mm. All were recovered at a depth to CG less than 1 m.

A one-to-one comparison of recovery depths and estimated penetration depths cannot be made because the UXO type (e.g., 81mm M374A3) of the majority of recovered ordnance is unknown. A general comparison can be made if it is assumed that the seven modeled ordnance are representative of each ordnance category (40 mm, 57 mm, etc.). Proceeding with that assumption, the values of the reported UXO recovery depths are generally within the estimates obtained using UXO-PenDepth with the minimum firing parameters (compare Fig. 16 and Table 6 with Figs. 10 and 11). Exceptions are the 60 mm and 81 mm. The 81-mm recovery depths are within the UXO-PenDepth maximum firing parameter estimates (Fig. 11), however 5% of the recovery depths of the 60 mm exceed those estimated using UXO-PenDepth.

Although the majority of the recovered UXO are within the UXO-PenDepth minimum firing parameter estimate, it is important to note that the majority of the recovery depths for a given UXO category are shallower than the shallowest UXO-PenDepth penetration estimate (except for the 60 mm and 81 mm) (Fig. 10, SNUM 5). For example, the shallowest penetration depth for a 40 mm penetrating a dry clay under minimum firing conditions is 32 cm (Table 5 and Fig. 10b). Referring to Fig. 16, 88% of 40 mm were recovered at a depth shallower than 32 cm. Possible discrepancies could be attributed to: 1) the modeled UXO in this study are not representative of the recovery data, 2) variations in firing parameters and methods of firing, 3) UXO movement after initial penetration and prior to recovery, and 4) differences in subsurface soil structure and soil parameters. Of these four factors, factors (1) and (2) probably contribute the least to the discrepancy between the UXO-PenDepth calculated depth of penetrations and the recovery depths presented in Fig. 16. We believe that the munitions modeled are representative of their category, and that any small modifications to their internal or external design would not result in significant changes in depth of penetration. Regarding the firing parameters or methods (factor (2)), if the standard or approved values or techniques were not used, then there could be significant differences in the calculated depth of penetration and actual penetration depth. However, it is assumed that the firing ranges follow the specifications provided for a given munitions, and therefore it is unlikely that variations in firing parameters and methods of firing account for the discrepancy between the calculated penetration and recovery depths. Factor (3), involving movement of a UXO prior to recovery, primarily from frost-heave action, could result in significant discrepancies between calculated penetration depth and recovery depth. This could occur in northern climates and, for a particular installation, could skew the data toward shallower recovery depths. However, because Fig. 16 includes data from recovery sites in different geographic regions, it is unlikely that factor (3) could account for the differences in penetration depth and reported recovery depths. Factor (4), differences in subsurface soil structure and soil parameters, is the primary factor that could account for significant differences between UXO-PenDepth penetration estimates and recovery depths. The calculated penetration depth is sensitive to the empirical soil resistance parameter SNUM. Also, the UXO-PenDepth estimates are based on half-space and limited two-layer soil models. The addition of subsurface layers and varying the layer parameters (thickness and SNUM) would result in different penetration depth estimates.

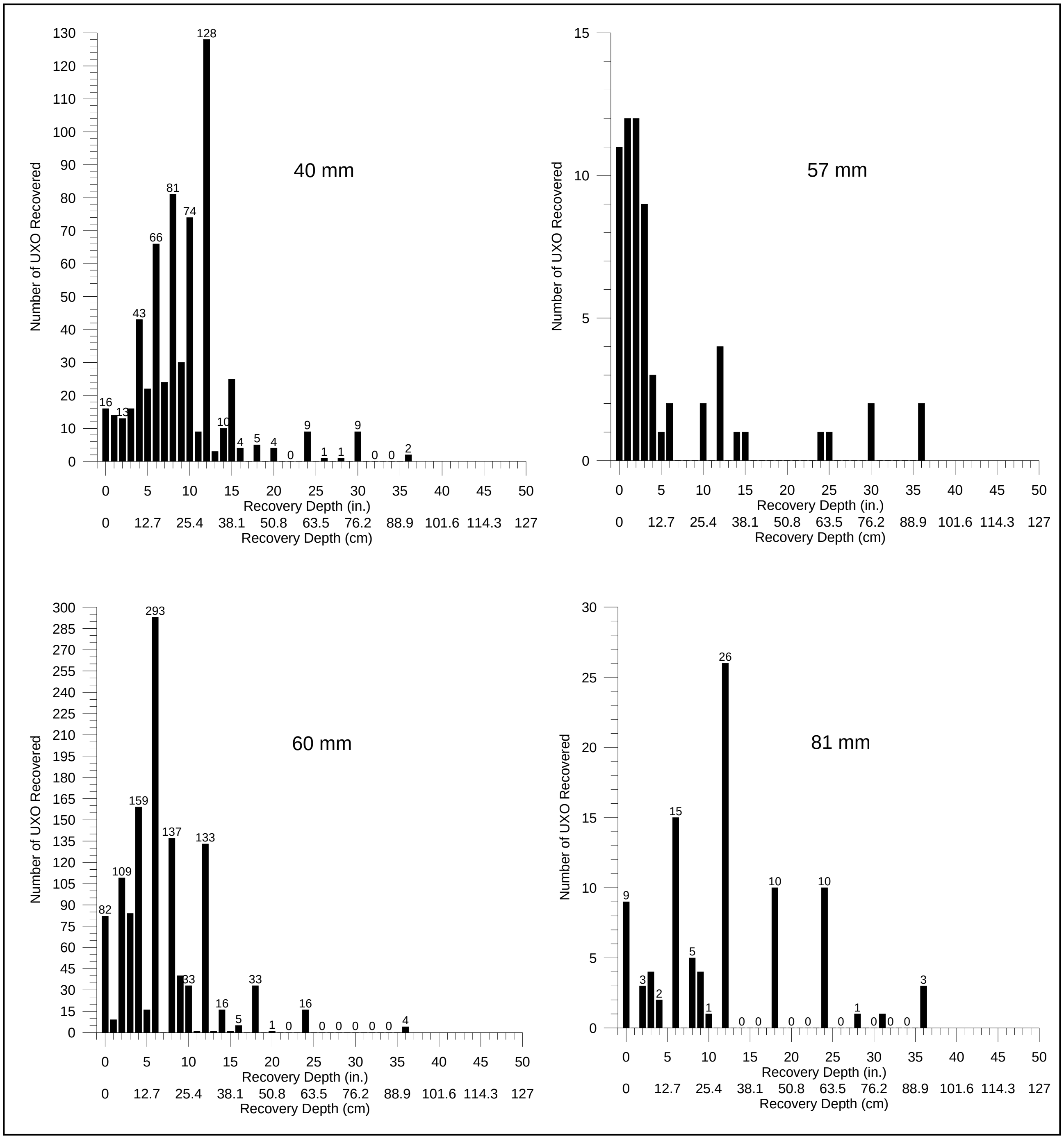


Figure 16. Recovery data obtained from the NDCEE database, queried 7 August 2009.

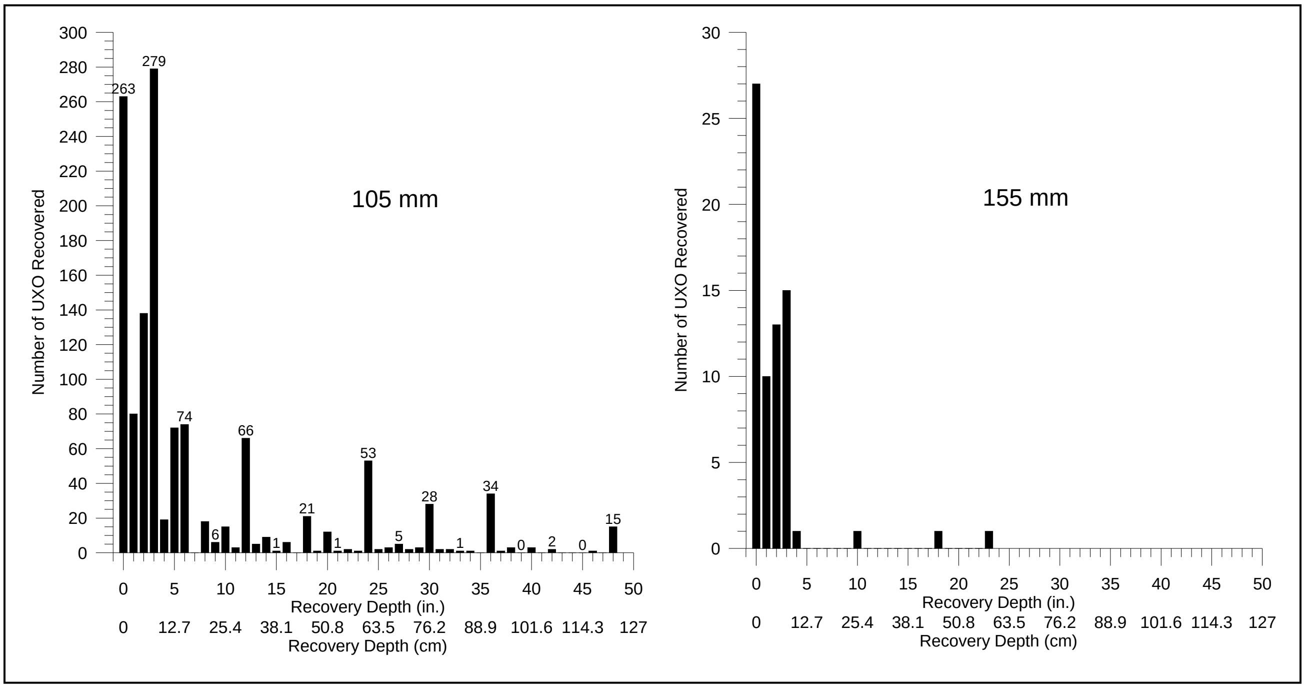


Figure 16. Concluded.

Table 6. Ancillary information from the NDCEE database for the munitions in Fig. 15.

Ordnance Size	Listing in NDCEE Database	Recovery Sites	Number Recovered
40 mm	40mm, 40mm HE	Southwestern Proving Grounds (SPG)	609
57 mm	57mm, 57mm HE, 57mm Practice	SPG, Fort Dix	64
60 mm	60mm, 60mm HE, 60mm Illumination	Camp Croft, Fort Dix, Camp Simms, Dolly Sods North Area, Dolly Sods Wilderness Area	1173
81 mm	81mm, 81mm HE, 81mm WP, 81mm Illumination	SPG, Camp Croft, East Elliot, Fort Dix, Dolly Sods Wilderness Area	94
105 mm	105mm, 105mm HE	SPG, Fort Dix	1253
155 mm	155mm, 155mm Smoke Signal	SPG	89

Table 7. Recovery data from three sites in Montana.

Site	# Recovered	Depth to CG (cm)
Limestone Hills		
105mm	1	12
155mm Illumination M118	2	18, 24
Chevallier Ranch		
105mm HE	1	35
105mm HEAT	1	23
155mm WP	2	26, 72
Guthrie Road		
81mm HE	4	8, 12, 16, 21
81mm Practice (inert)	33	0 to 19

8.0 COST ASSESSMENT

The primary cost in a typical munitions response effort is attributed to labor (Young and Fanning, 2006). The labor costs generally overshadow the costs of geophysical equipment, vegetation removal equipment and excavation implements and/or machinery. There may be exceptions when more sophisticated geophysical systems are used, such as airborne, vehicle-towed arrays, or mechanized dig and sift operations. Knowledge of the expected depth of munitions can aid in selection of the appropriate geophysical sensors, estimating if multiple clearance sweeps are required for the designated future site use, and providing reasonable cost estimates for munitions response operations. Presently, munitions response managers base clearance depth estimates on ordnance recovery information in historical databases and records available at an installation. Site regulators use these same records to determine if an UXO contaminated site has been cleared to a safe depth. Typical clearance costs per acre for a digital geophysical mapping survey are estimated at $15,500 (based on values reported in Young and Fanning (2006) with a 10% increase in costs over three years). Requiring UXO clearance depths greater than penetration depths because of a lack of reliable ordnance penetration estimates and “just to be safe” can easily increase munitions response costs on the order of millions of dollars. Integration of UXO-PenDepth into the munitions response process could result in significant cost savings.

9.0 IMPLEMENTATION ISSUES

Two primary concerns regarding implementation of UXO-PenDepth involve the acquisition of ordnance parameters, physical characteristics and firing information, and the use of an empirical soil resistance parameter. The munitions database in UXO-PenDepth contains ten ordnance input models plus the 1/7 SAP scale model. Although the input models range in size from 20 mm to a 100-lb bomb, these models do not adequately represent the multitude of ordnance types found on firing ranges. The munitions database should be expanded to represent the most common munitions currently found or suspected to exist on firing ranges, and newer munitions being used. Although the UXO-PenDepth user has the ability to generate an ordnance input file, some of the information needed to generate the input file requires access to databases

that typically are not accessible by the general population. The inclusion of additional ordnance input files would enhance the program and be more useful to regulators and those involved in munitions response efforts.

The properties of the soil model used in UXO-PenDepth are represented by the empirical soil resistance parameter SNUM. Typical values for SNUM range between 5 and 12 for sand/silt/clay mixtures under dry to wet moisture conditions. Although use of an empirical soil resistance parameter is adequate for estimating penetration depth, the development of new forcing functions would allow generation of a site-specific penetration resistance. This would allow the ordnance depth of penetration to be modeled specifically to a site's soil conditions. In situ soil properties would be required, but could be obtained with hand-held cone penetrometers and moisture meters.

The application of UXO-PenDepth for the estimation of ordnance penetration depths could ease the tension between those involved in munitions response efforts and regulators that are entrusted with the public's safety and responsible for ensuring an UXO contaminated site is adequately cleared. Those involved in clearance operations will welcome a physics-based estimate for depth of penetration; regulators may be more resistant to its use. Based on limited historical data, the depth of penetration estimates using UXO-PenDepth are generally greater than recovery depths. This discrepancy may not alleviate the differing opinions between munitions response managers and regulators, however it may lead to more reasonable clearance depths that satisfy all parties involved.

The UXO-PenDepth software is available for public release, but its distribution is limited to government agencies and their contractors. It is distributed through the U.S. Army Engineer Research and Development Center, Vicksburg, Mississippi.

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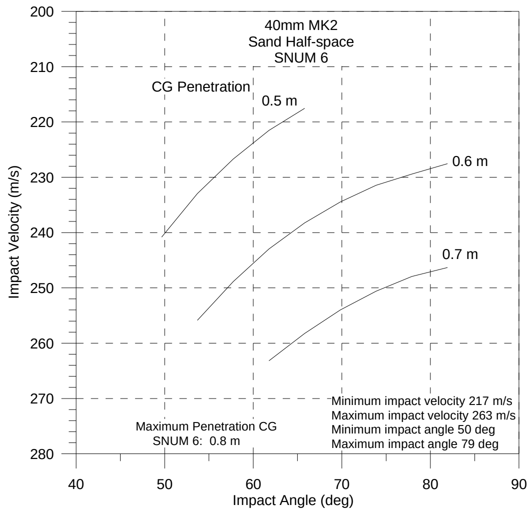
APPENDICES

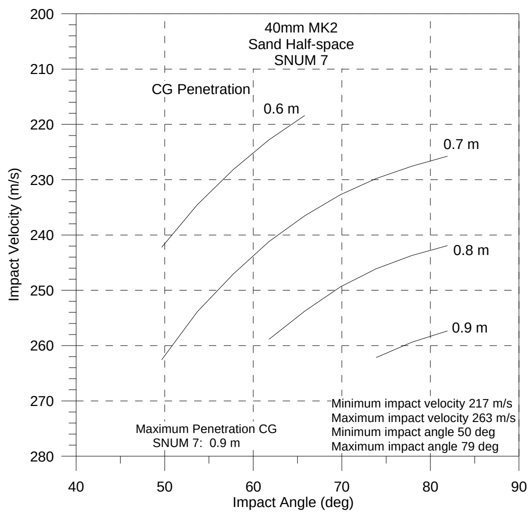
Appendix A: Points of Contact

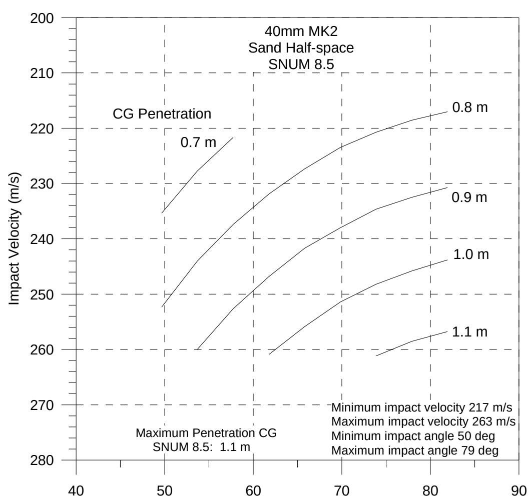
POINT OF CONTACT Name	ORGANIZATION Name Address	Phone Fax Email	Role in Project
Janet E. Simms	U.S. Army Engineer Research and Development Center 3909 Halls Ferry Road Vicksburg, MS 39180	601-634-3493 601-634-3453 Janet.E.Simms@usace.army.mil	PI—UXO PenDepth simulations; data analysis; write report
Rebecca P. Berger	U.S. Army Engineer Research and Development Center 3909 Halls Ferry Road Vicksburg, MS 39180	601-634-4252 601-634-2642 Rebecca.P.Berger@usace.army.mil	PI—generated input models for UXO-PenDepth; quality assurance

Appendix B: Depth Penetration Range (DPR) Plots for Half-Space Soil Scenarios

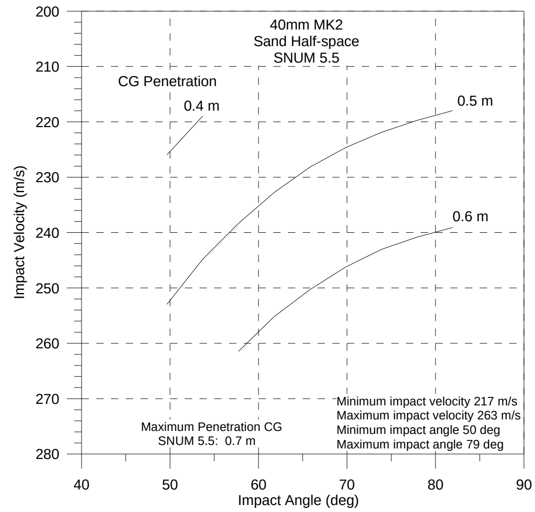
40mm MK2
Sand Half-space

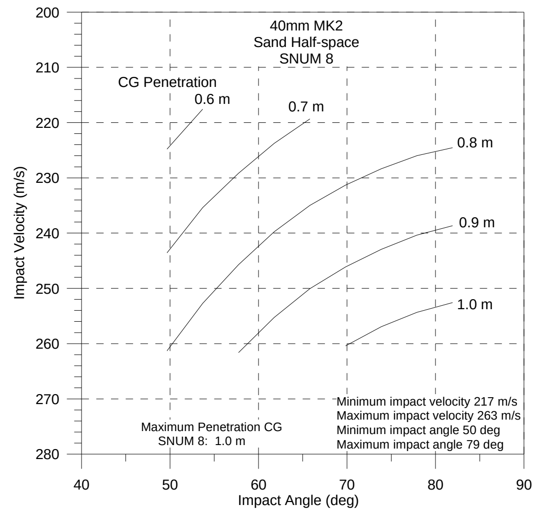


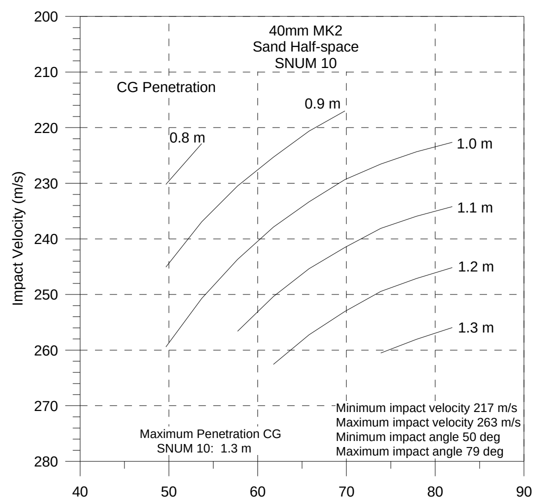




40mm MK2
Silt Half-space

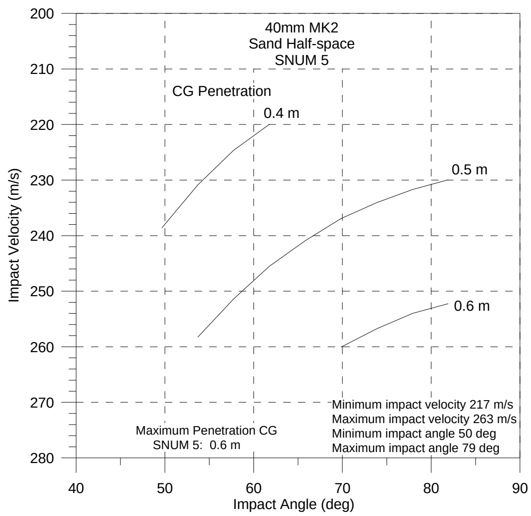


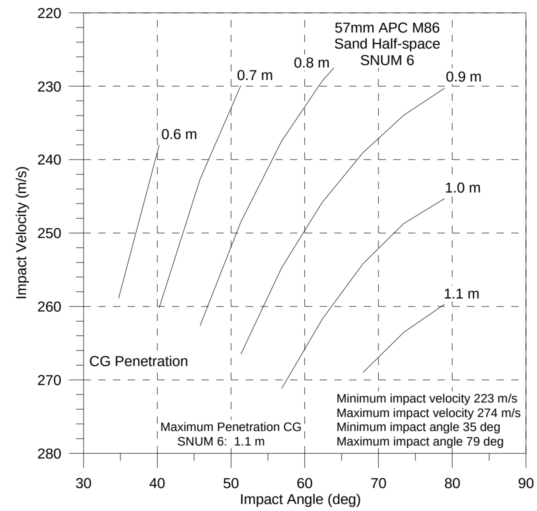


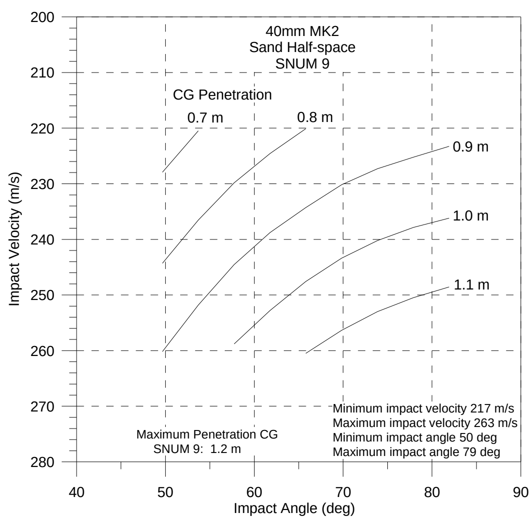


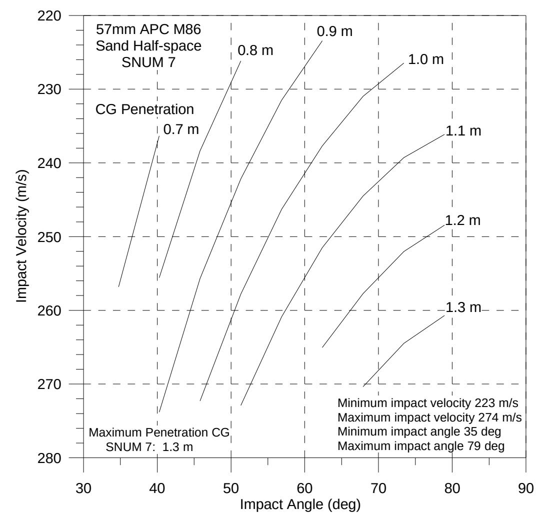
40mm MK2
Clay Half-space

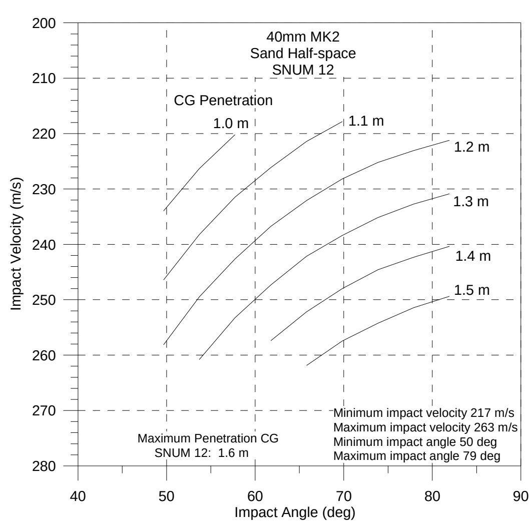
57mm APC M86
Sand Half-space

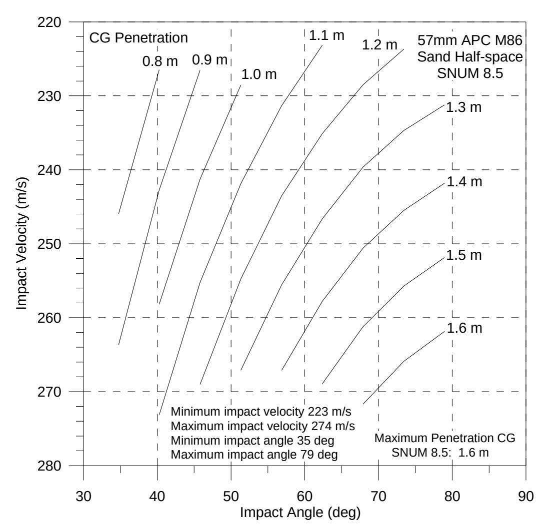




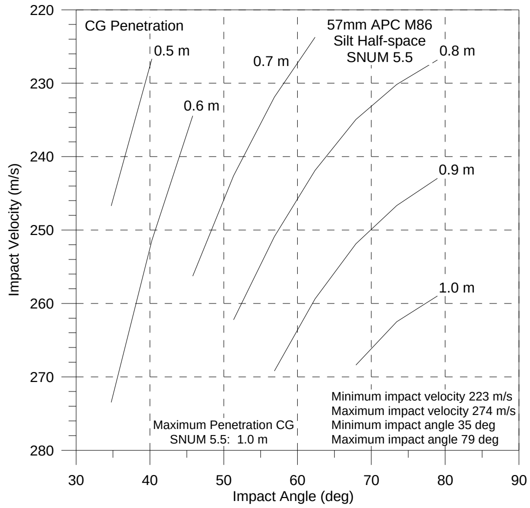


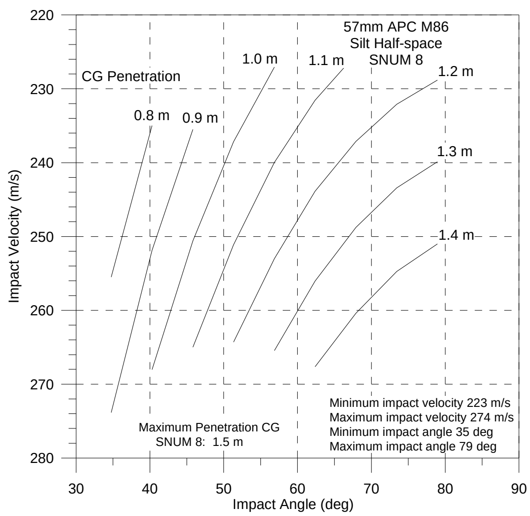


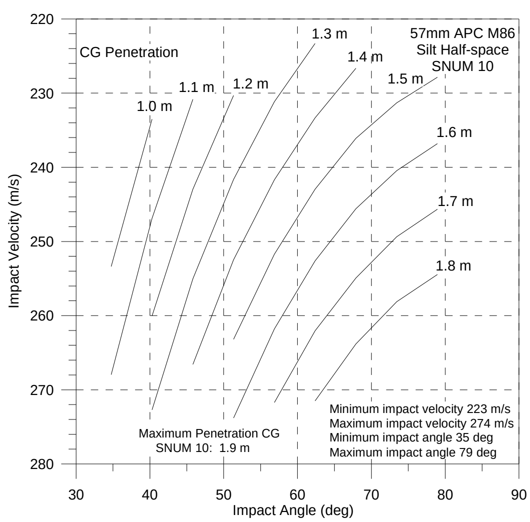




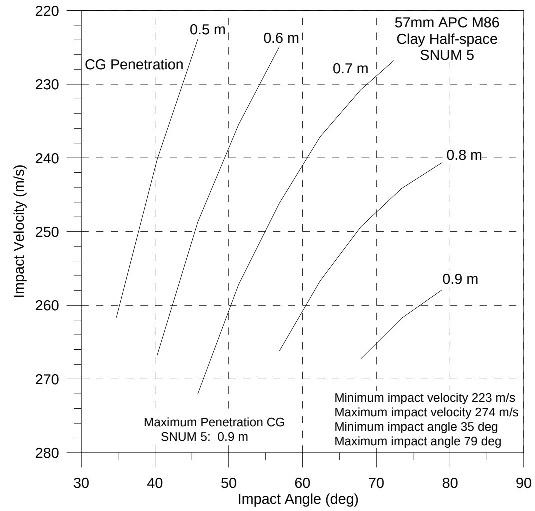
57mm APC M86
Silt Half-space

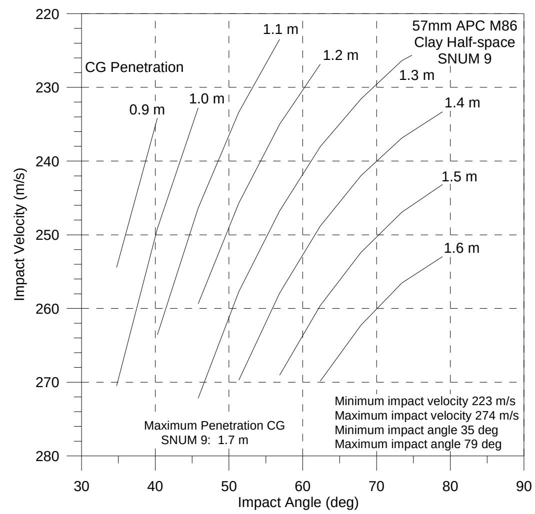


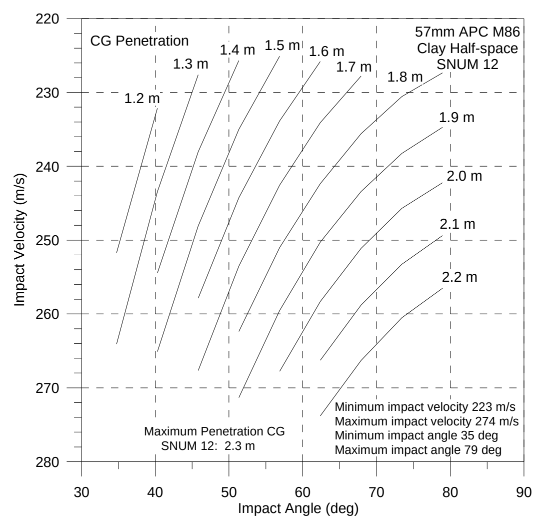




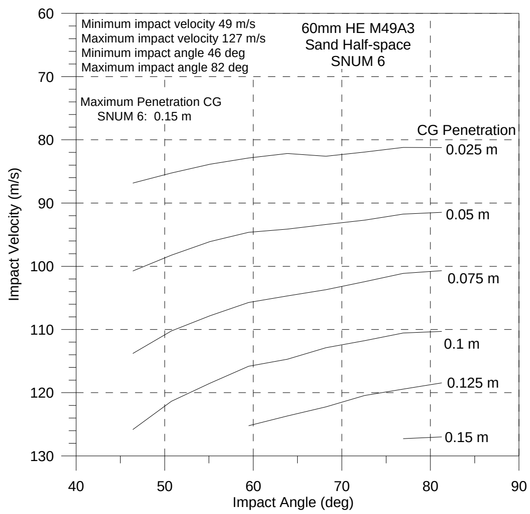
57mm APC M86
Clay Half-space

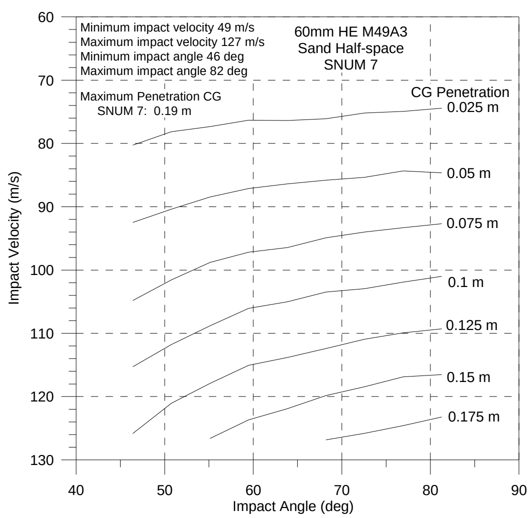


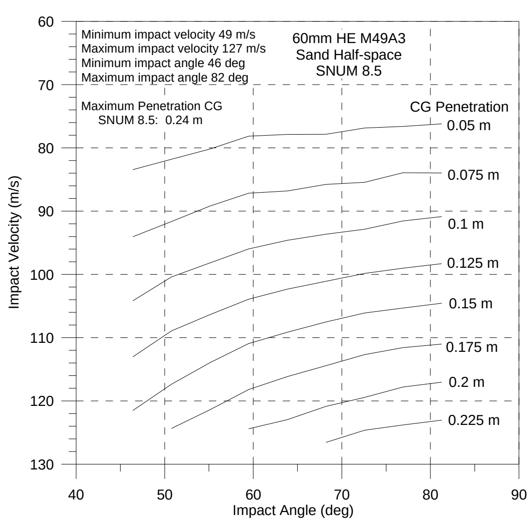




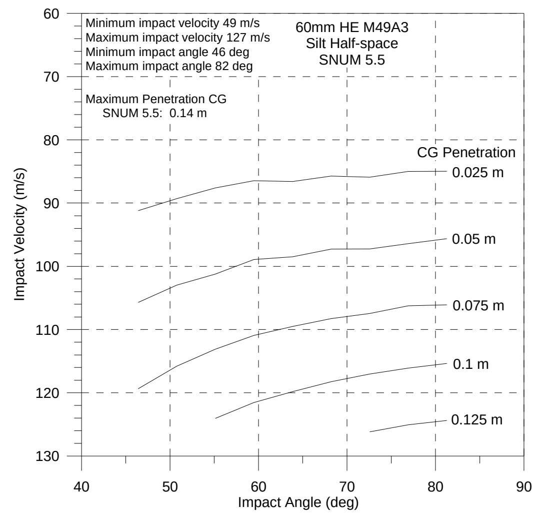
60mm M49A3
Sand Half-space

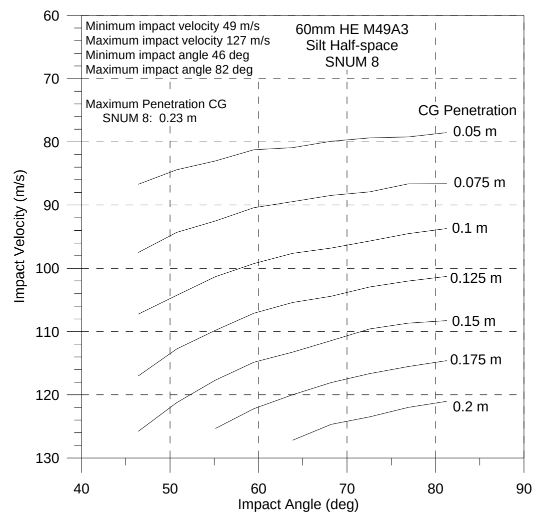


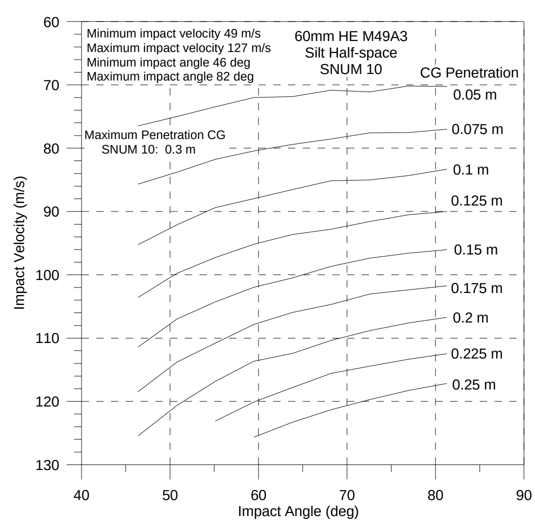




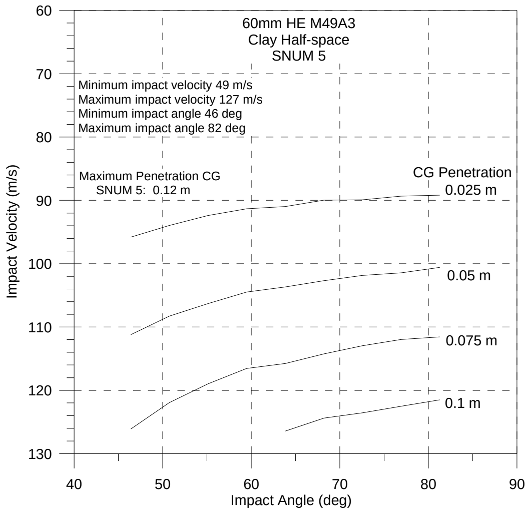
60mm M49A3
Silt Half-space

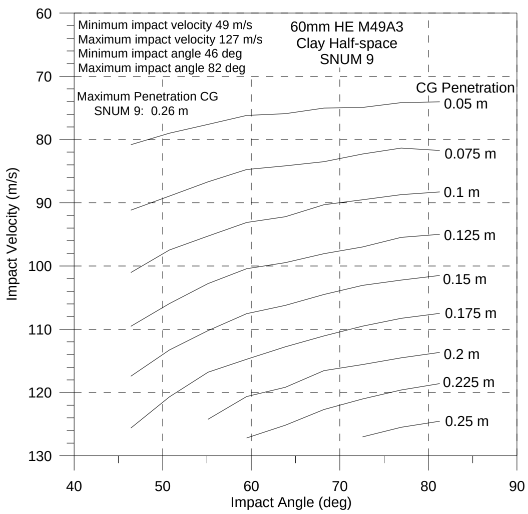


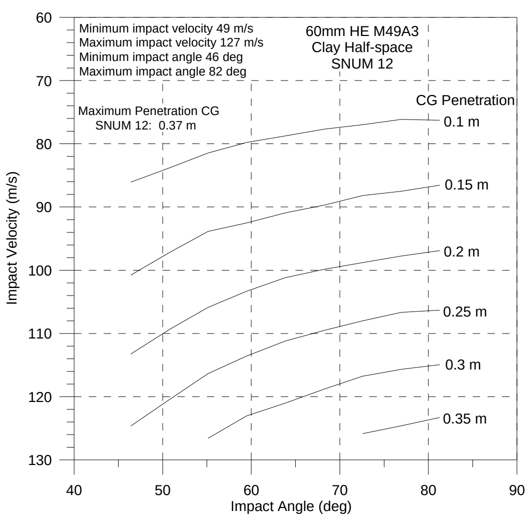




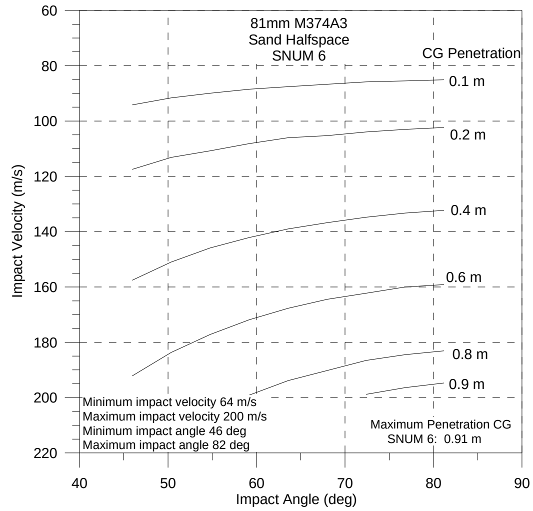
60mm M49A3
Clay Half-space

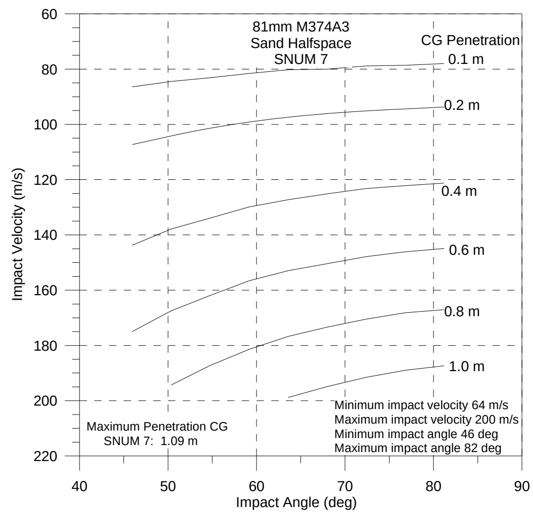


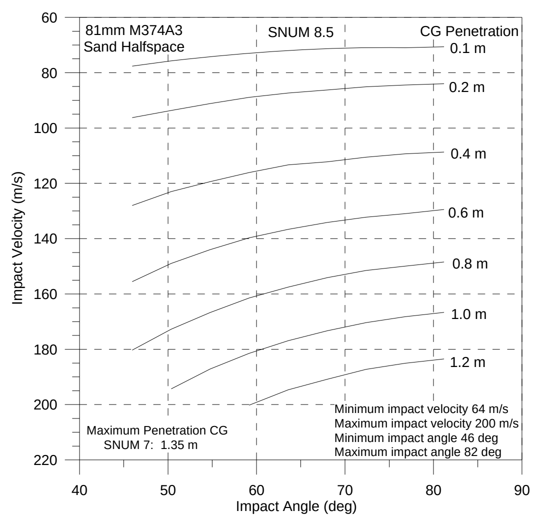




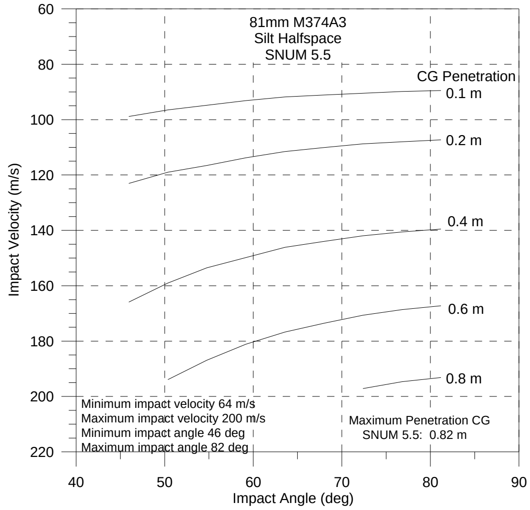
81mm M374
Sand Half-space

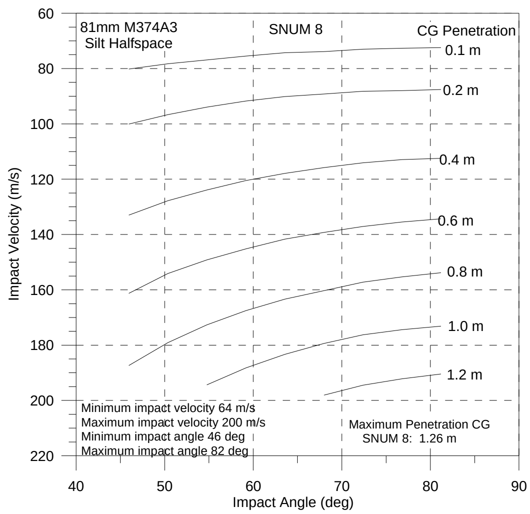


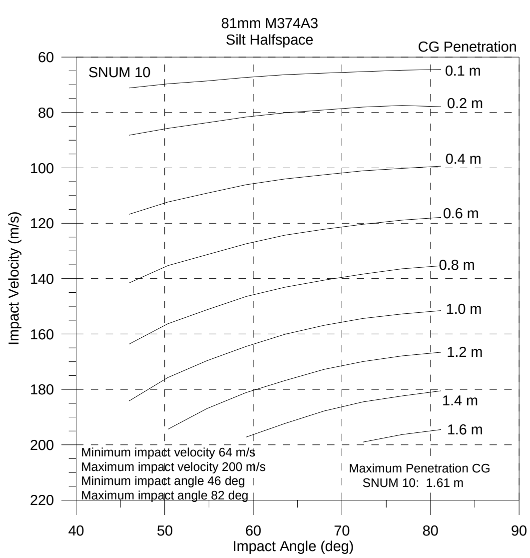




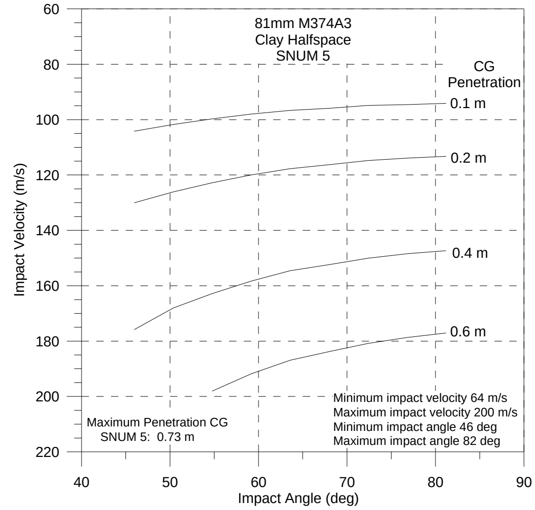
81mm M374
Silt Half-space

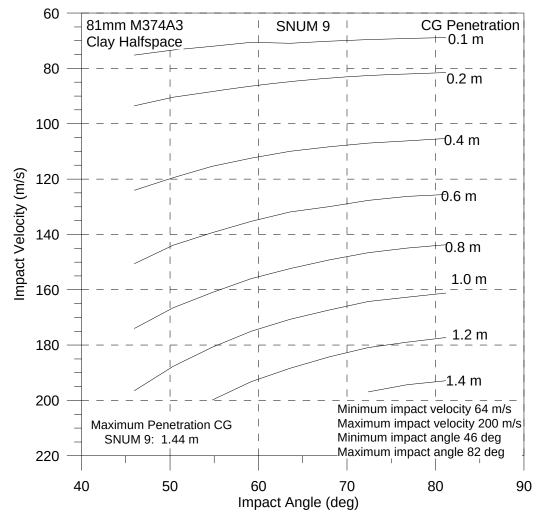


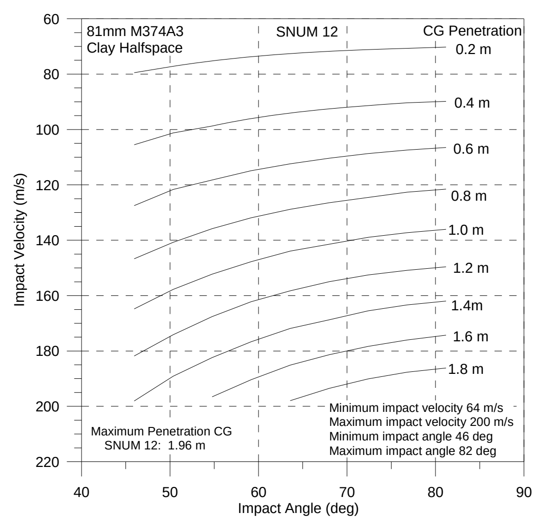




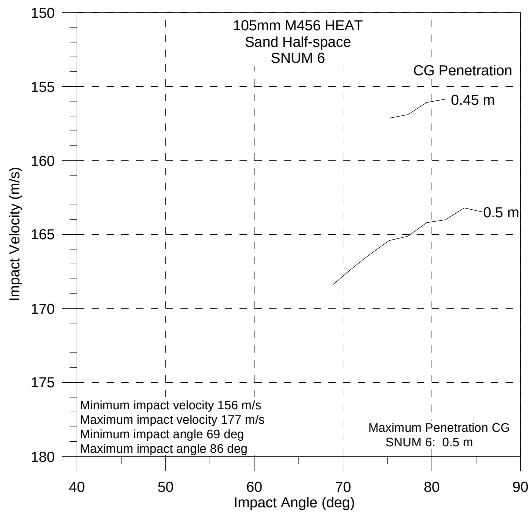
81mm M374
Clay Half-space

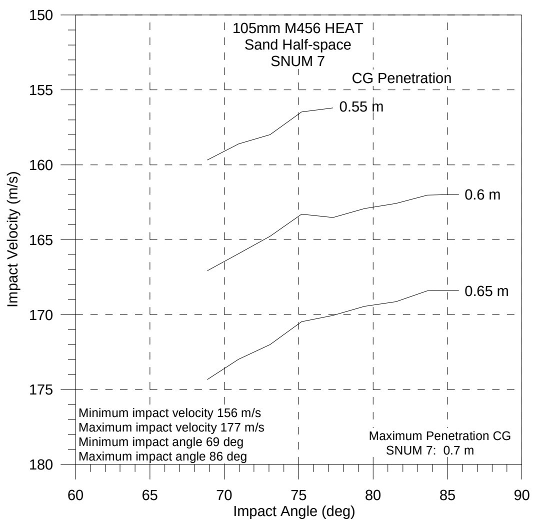


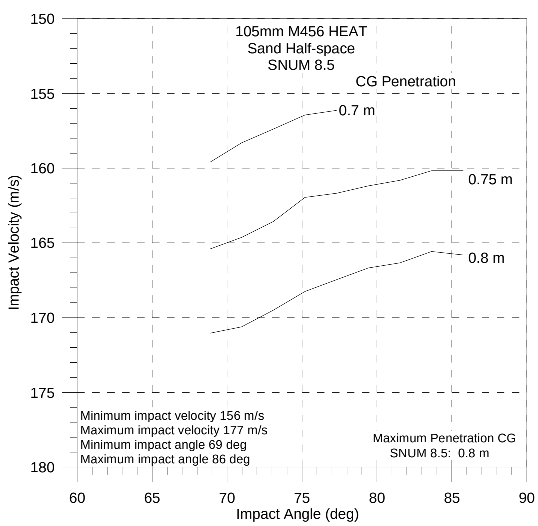




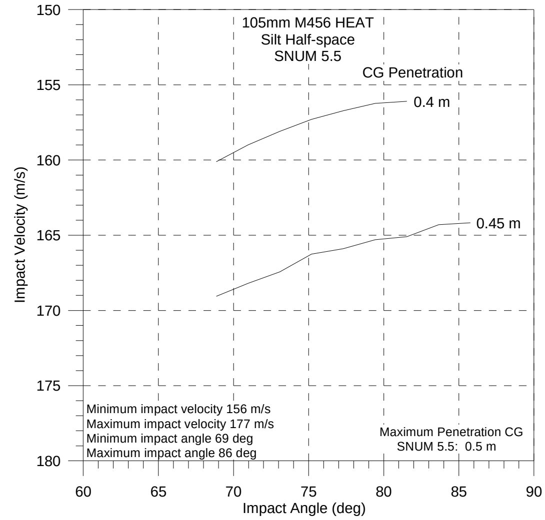
105mm HEAT M456
Sand Half-space

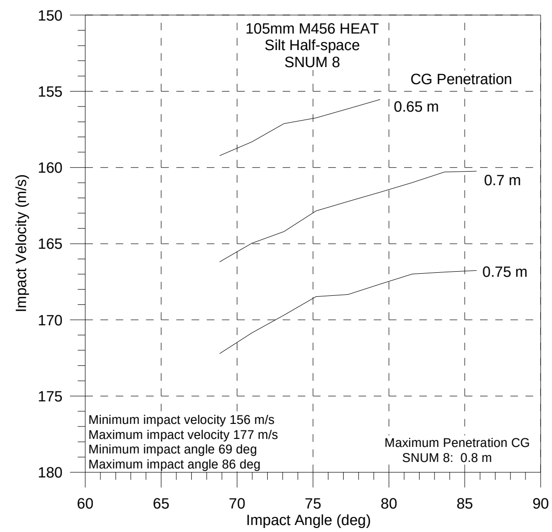


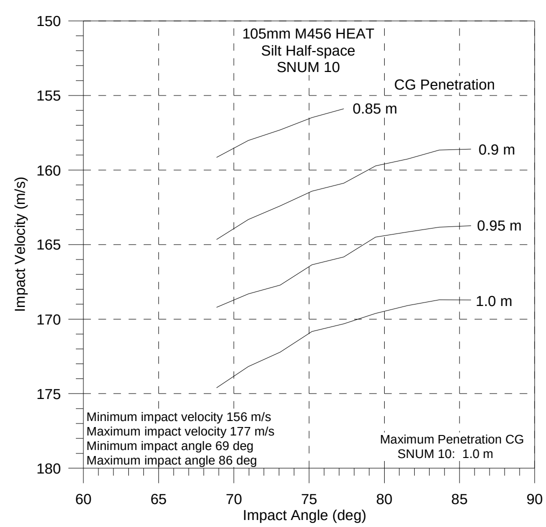




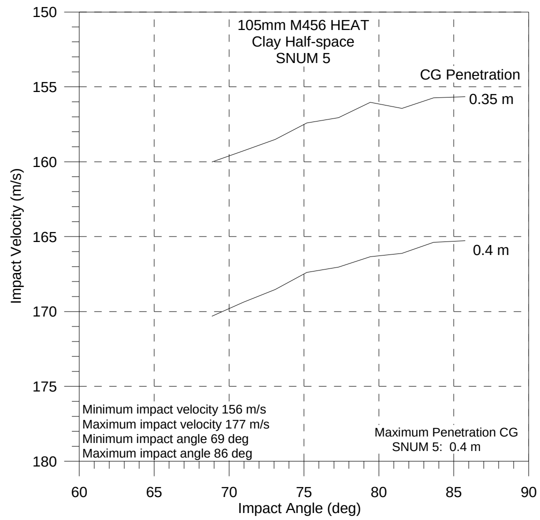
105mm HEAT M456
Silt Half-space

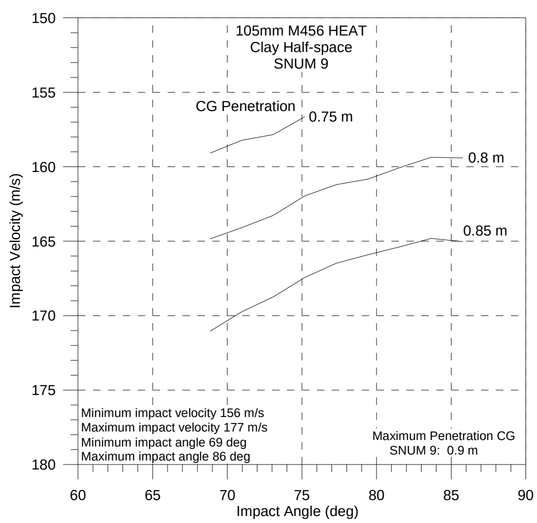


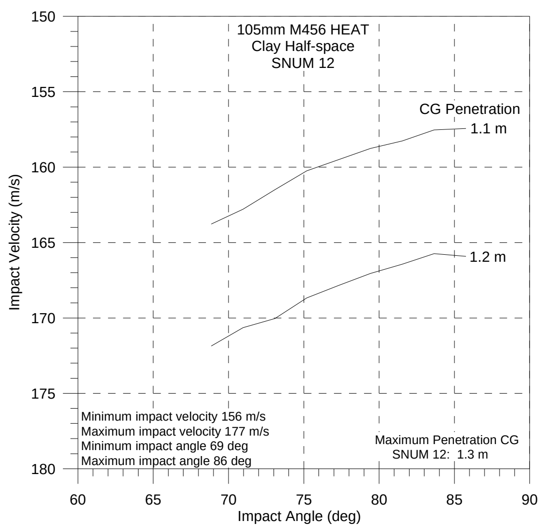




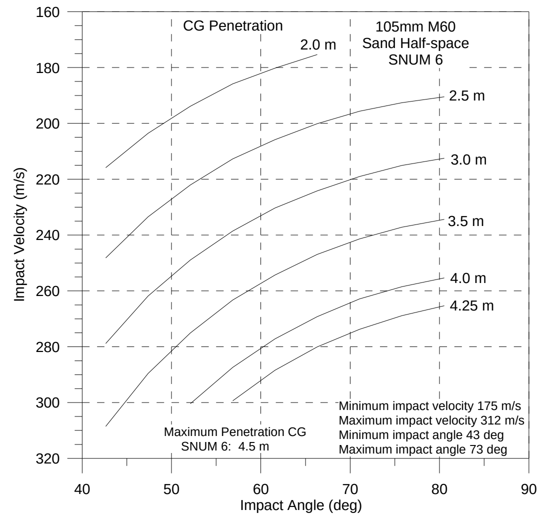
105mm HEAT M456
Clay Half-space

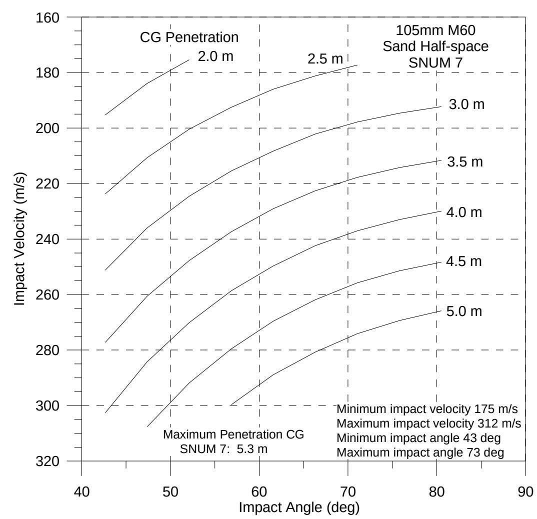


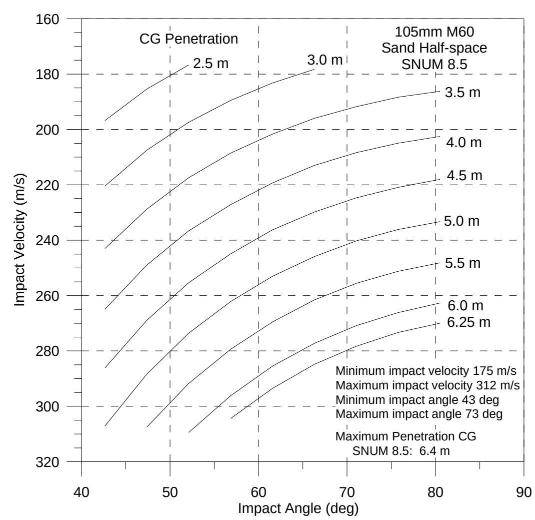




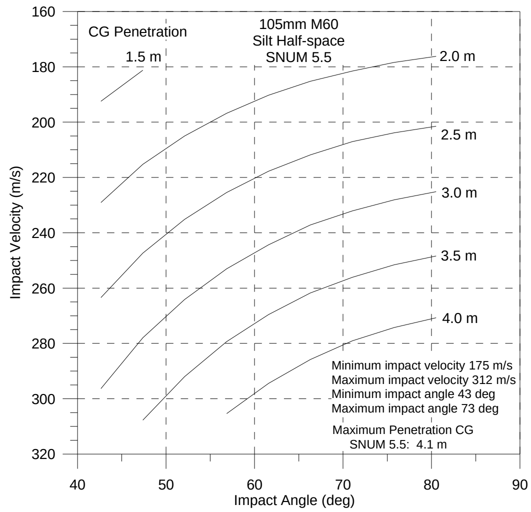
105mm M60
Sand Half-space



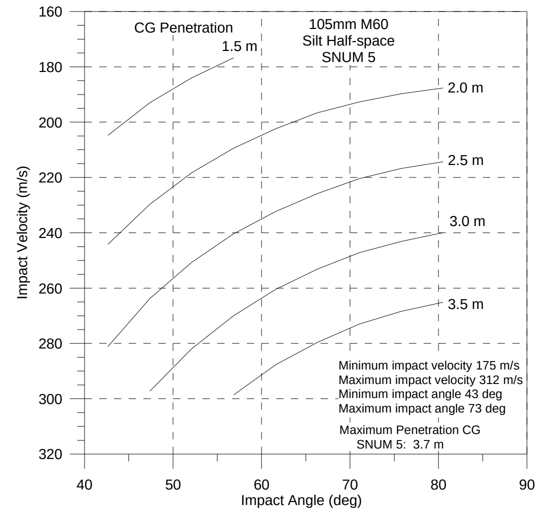


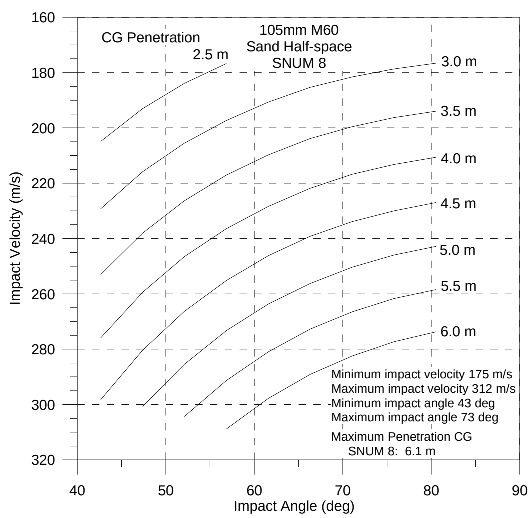


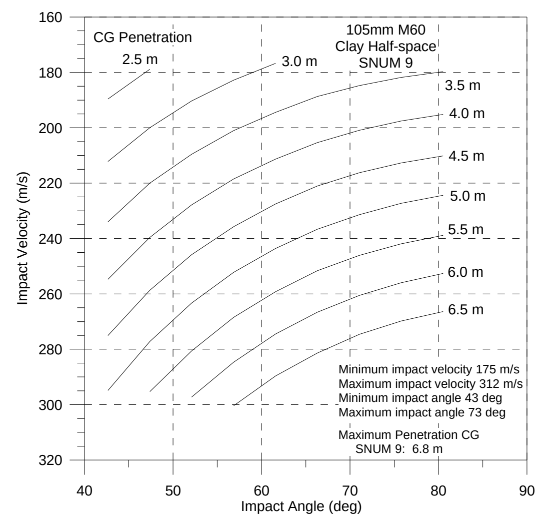
105mm M60
Silt Half-space

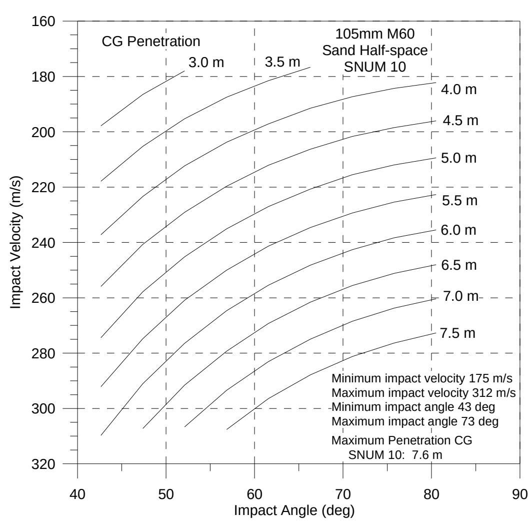


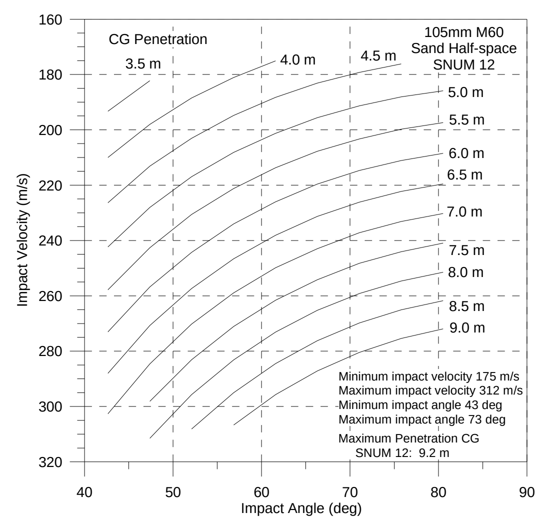
105mm M60
Clay Half-space



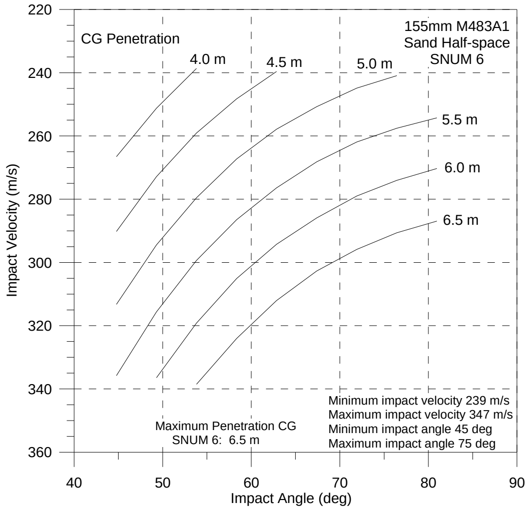


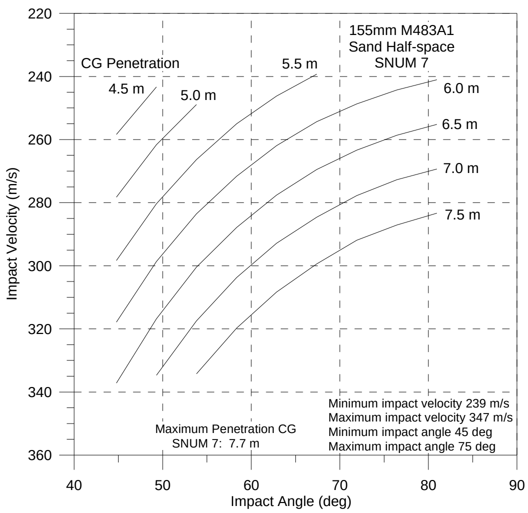


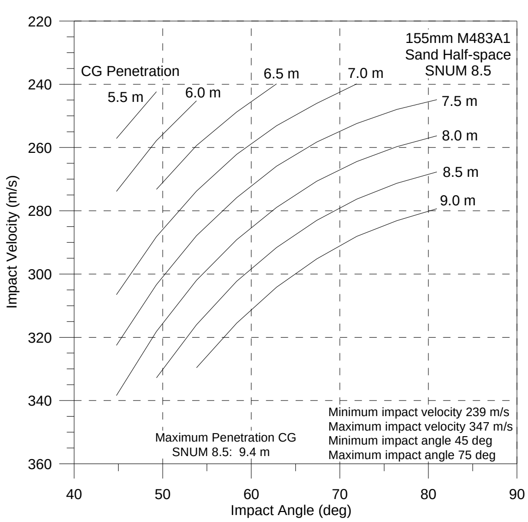




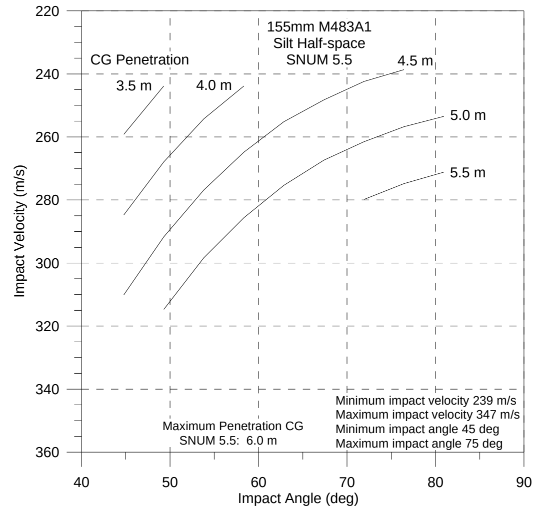
155mm M483A1 Sand Half-space

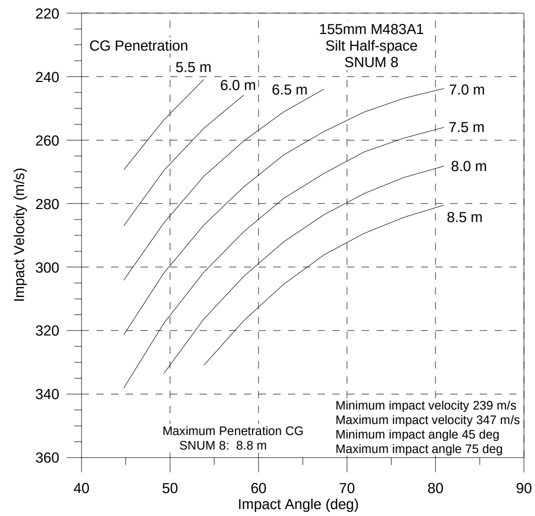


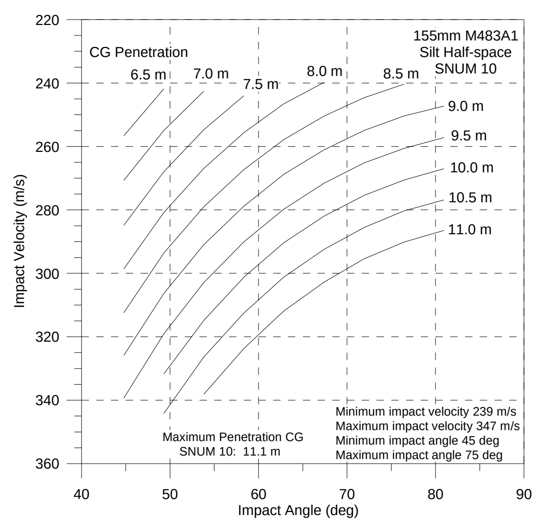




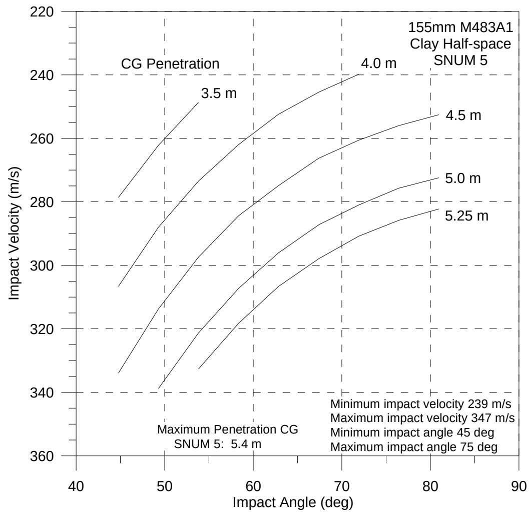
155mm M483A1 Silt Half-space

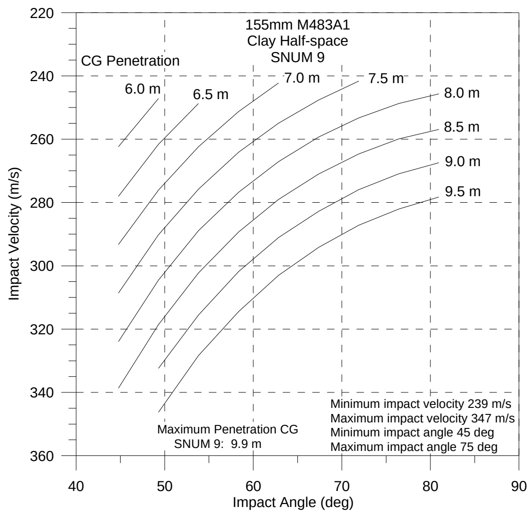


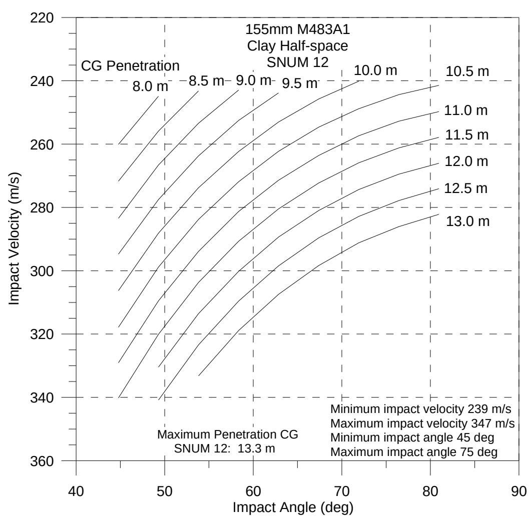




155mm M483A1
Clay Half-space



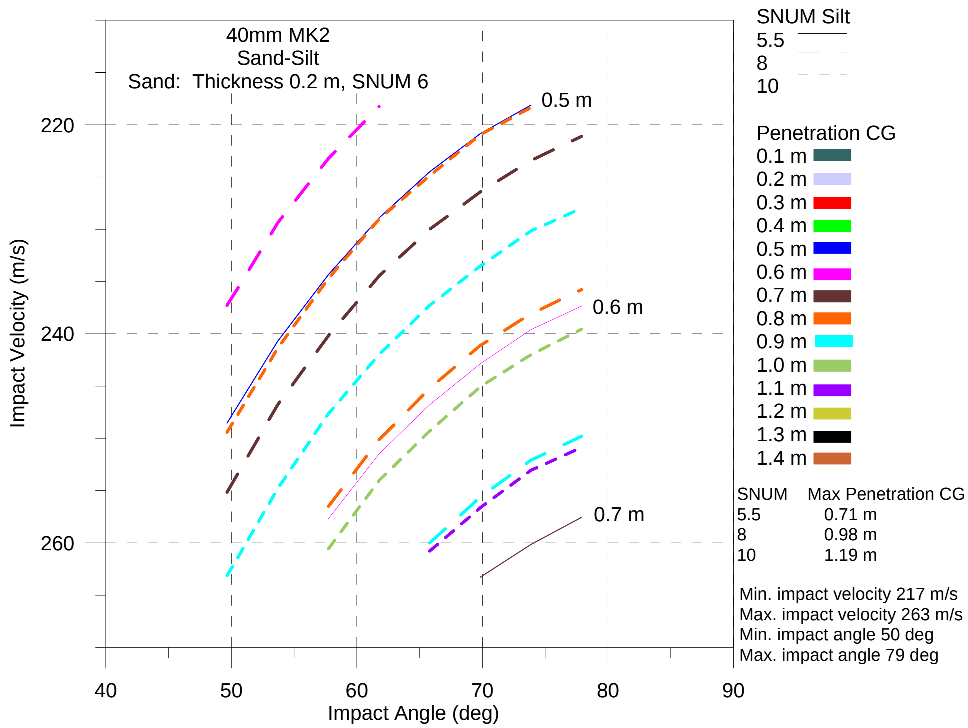


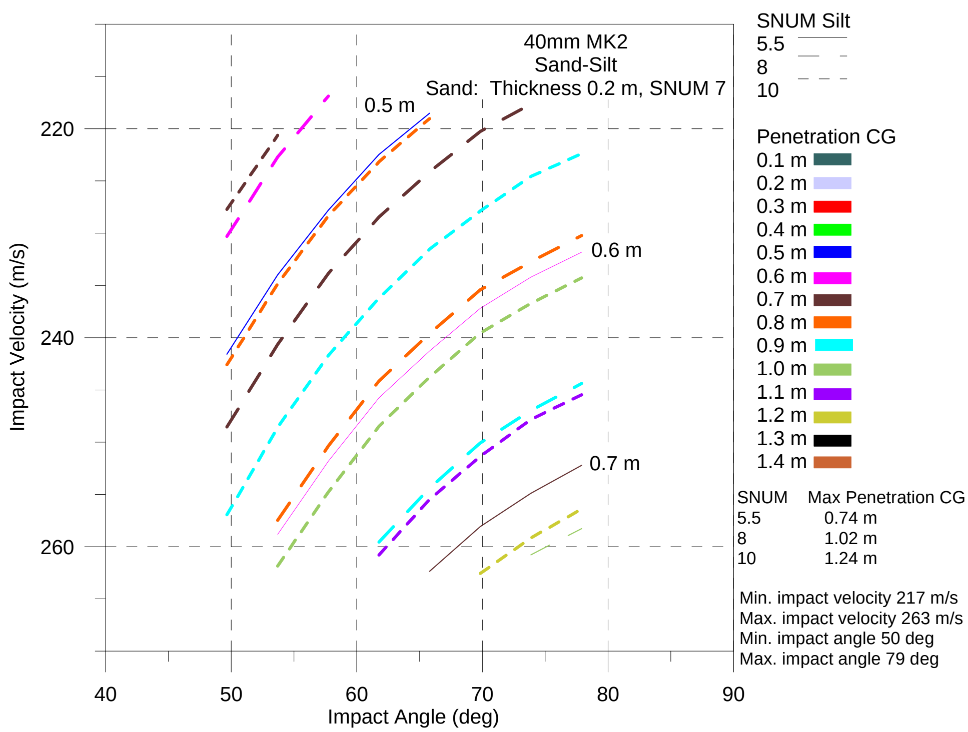


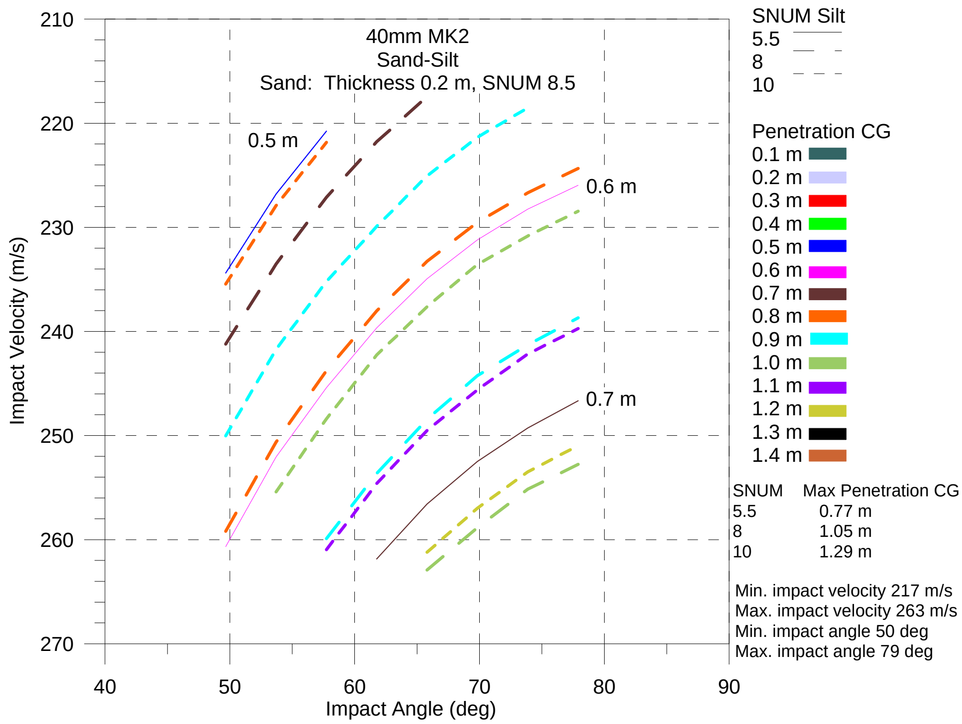
Appendix C: Depth Penetration Range (DPR) Plots for 2-Layer Soil Scenarios

40mm MK2

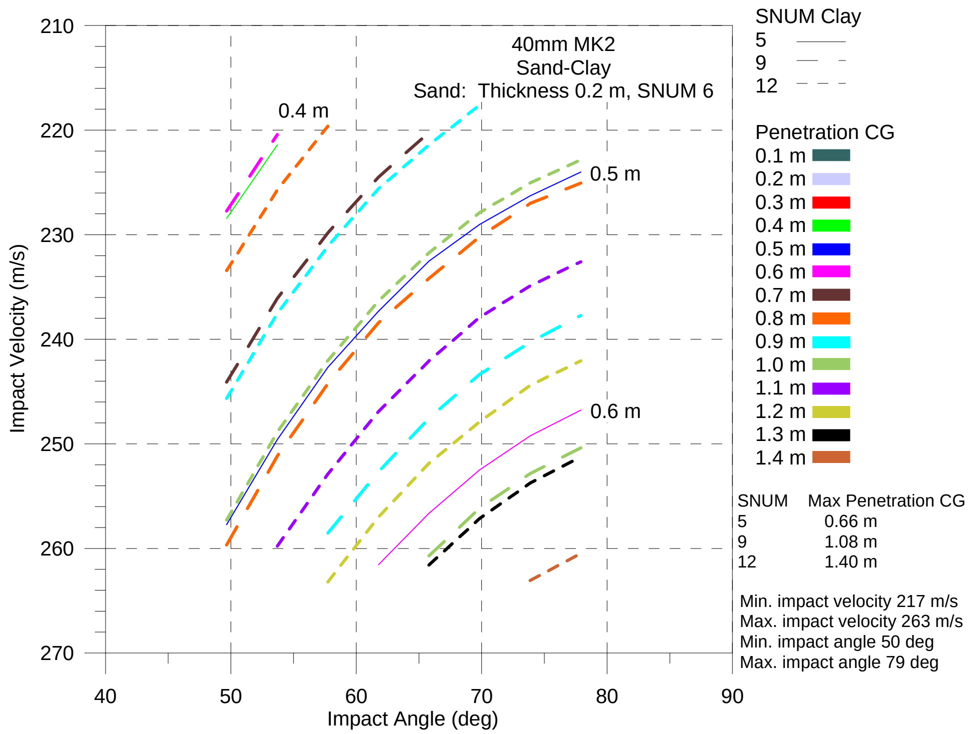
Sand-Silt

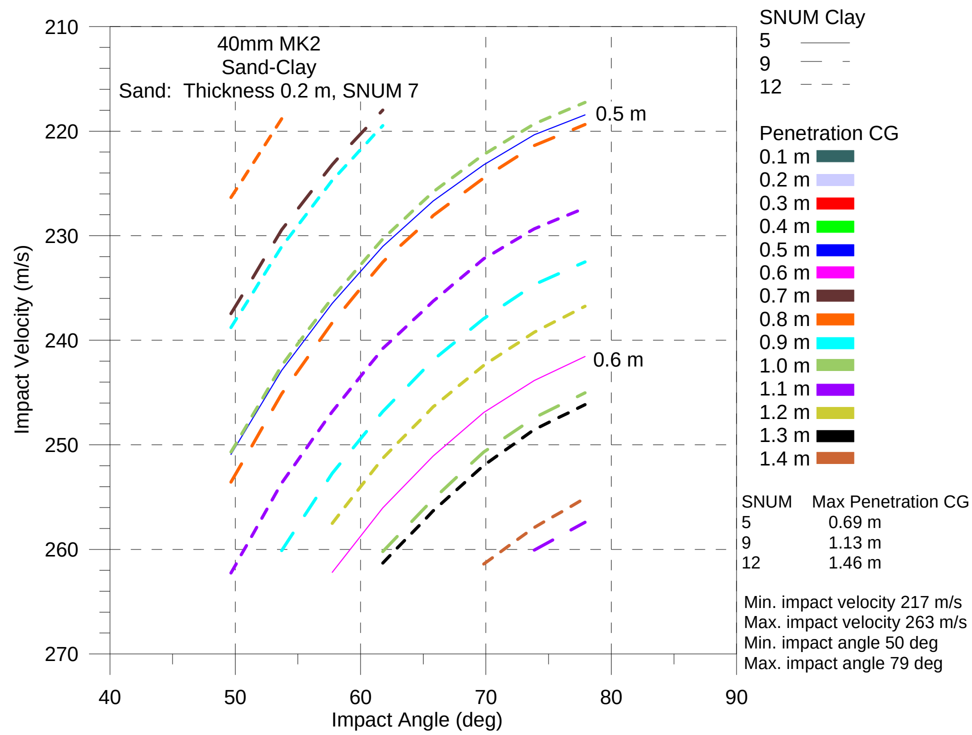


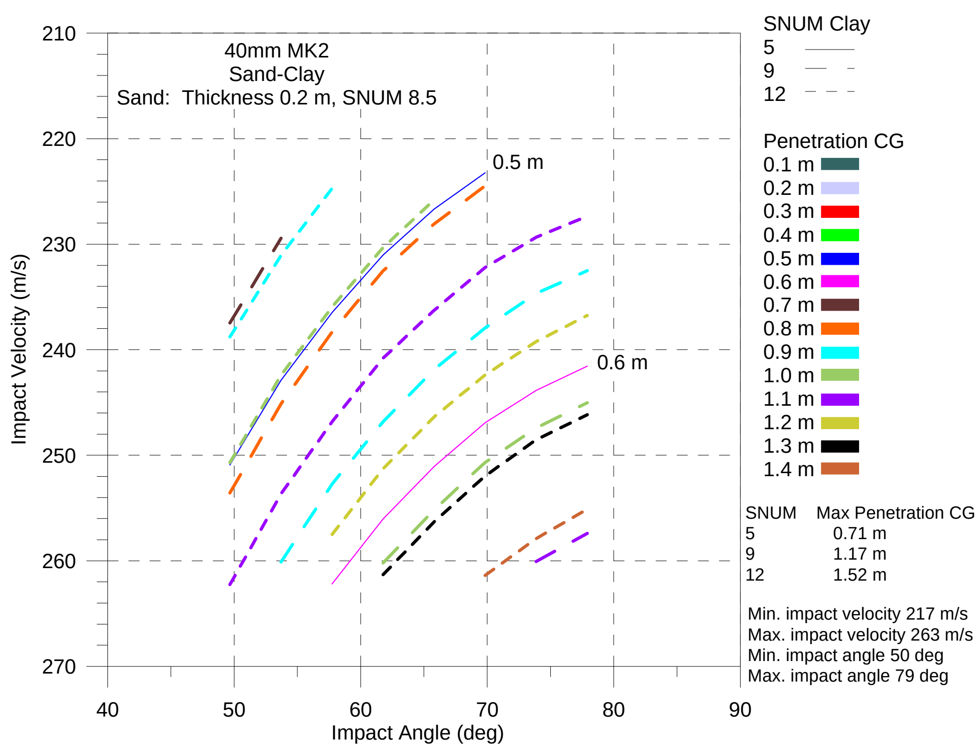



40mm MK2
Sand-Silt
Sand: Thickness 0.2 m, SNUM 8.5
0.5 m
0.6 m
0.7 m
Impact Velocity (m/s)
Impact Angle (deg)
SNUM Silt
5.5
8
10
Penetration CG
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
1.3 m
1.4 m
SNUM Max Penetration CG
5.5 0.77 m
8 1.05 m
10 1.29 m
Min. impact velocity 217 m/s
Max. impact velocity 263 m/s
Min. impact angle 50 deg
Max. impact angle 79 deg

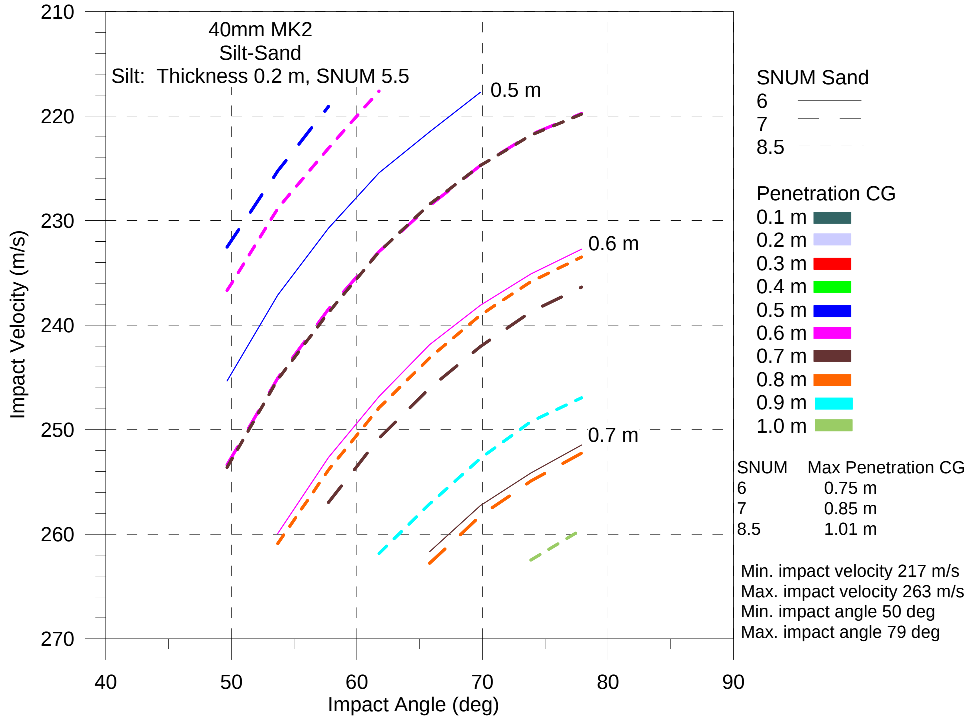
Sand-Clay


40mm MK2
Sand-Clay
Sand: Thickness 0.2 m, SNUM 6
0.4 m
0.5 m
0.6 m
Impact Velocity (m/s)
Impact Angle (deg)
SNUM Clay
5
9
12
Penetration CG
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
1.3 m
1.4 m
SNUM Max Penetration CG
5 0.66 m
9 1.08 m
12 1.40 m
Min. impact velocity 217 m/s
Max. impact velocity 263 m/s
Min. impact angle 50 deg
Max. impact angle 79 deg

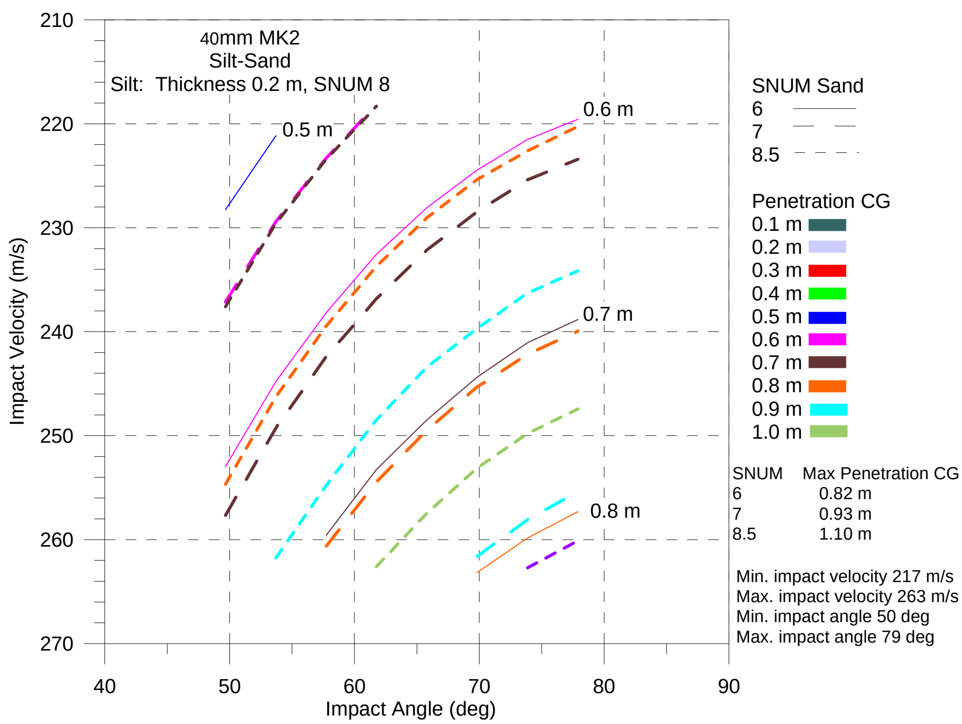

40mm MK2
Sand-Clay
Sand: Thickness 0.2 m, SNUM 7
0.5 m
0.6 m
Impact Velocity (m/s)
Impact Angle (deg)
SNUM Clay
5
9
12
Penetration CG
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
1.3 m
1.4 m
SNUM Max Penetration CG
5 0.69 m
9 1.13 m
12 1.46 m
Min. impact velocity 217 m/s
Max. impact velocity 263 m/s
Min. impact angle 50 deg
Max. impact angle 79 deg


40mm MK2
Sand-Clay
Sand: Thickness 0.2 m, SNUM 8.5
0.5 m
0.6 m
Impact Velocity (m/s)
Impact Angle (deg)
SNUM Clay
5
9
12
Penetration CG
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
1.3 m
1.4 m
SNUM Max Penetration CG
5 0.71 m
9 1.17 m
12 1.52 m
Min. impact velocity 217 m/s
Max. impact velocity 263 m/s
Min. impact angle 50 deg
Max. impact angle 79 deg

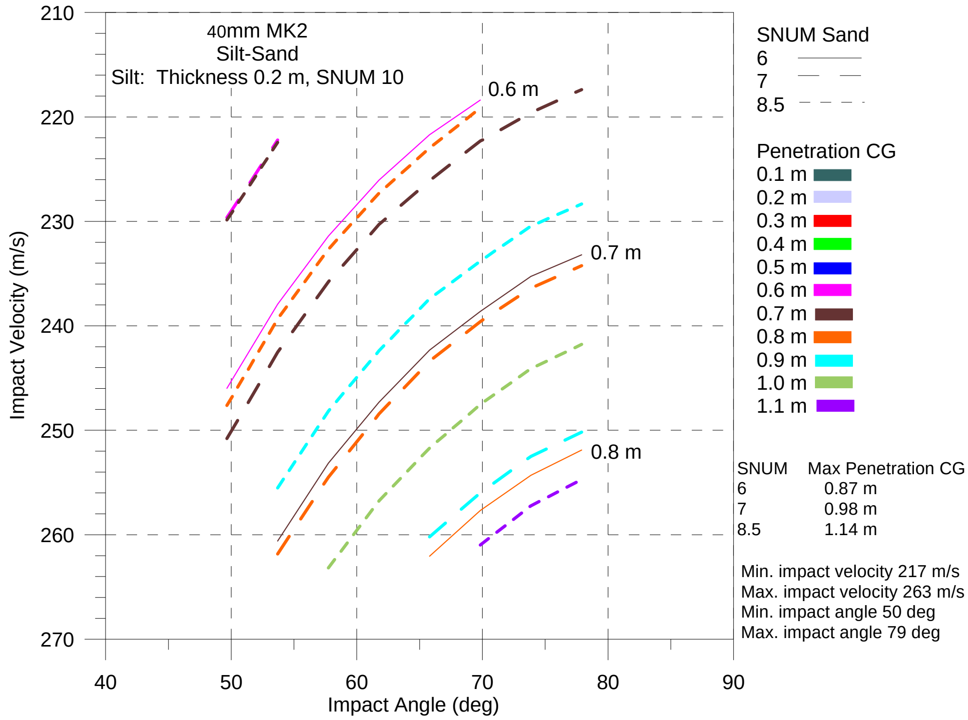
Silt-Sand



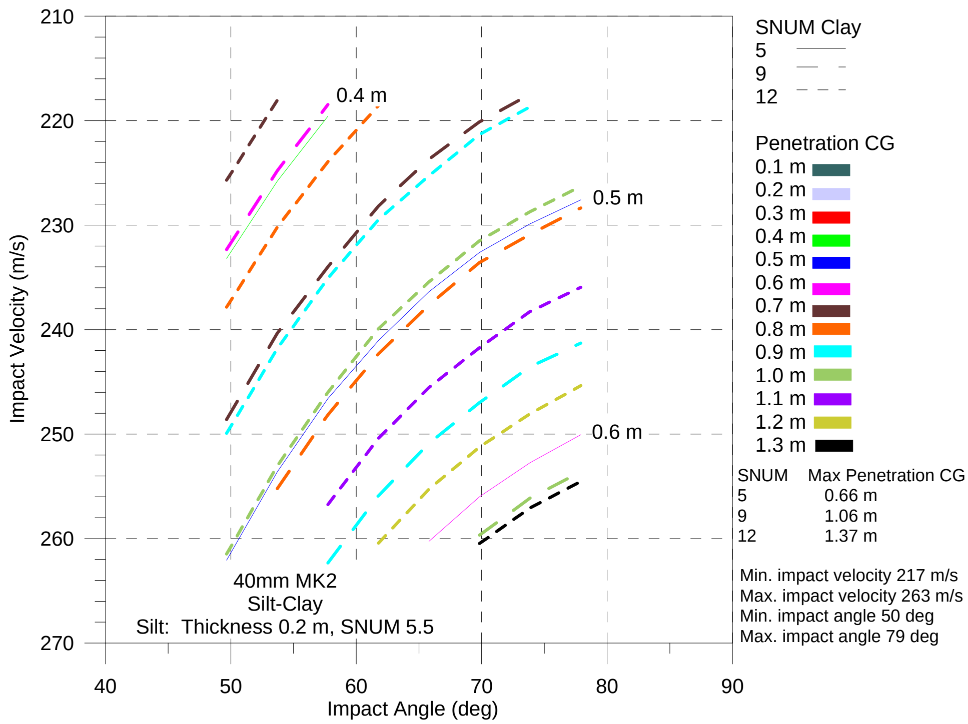
40mm MK2
Silt-Sand
Silt: Thickness 0.2 m, SNUM 5.5
0.5 m
0.6 m
0.7 m
Impact Velocity (m/s)
Impact Angle (deg)
SNUM Sand
6
7
8.5
Penetration CG
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
SNUM Max Penetration CG
6 0.75 m
7 0.85 m
8.5 1.01 m
Min. impact velocity 217 m/s
Max. impact velocity 263 m/s
Min. impact angle 50 deg
Max. impact angle 79 deg

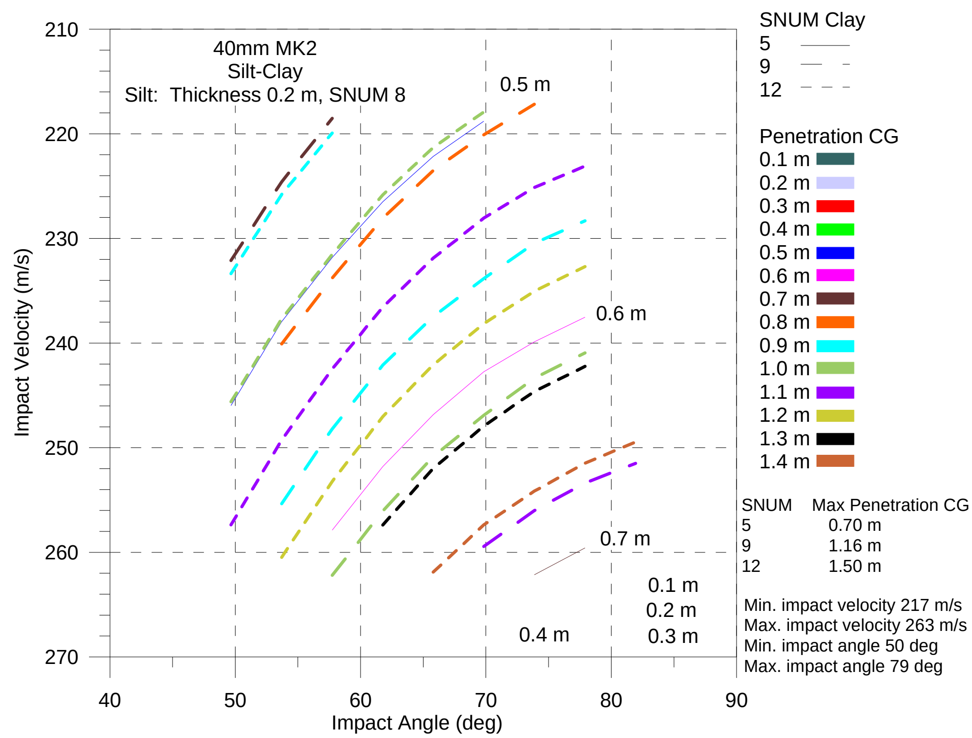


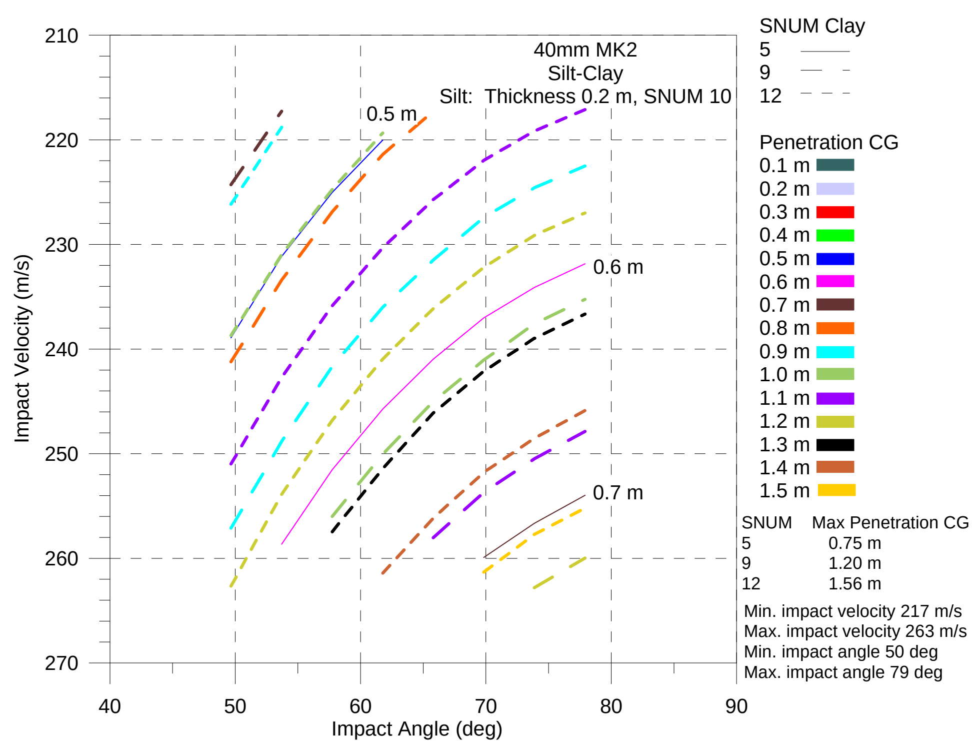
40mm MK2
Silt-Sand
Silt: Thickness 0.2 m, SNUM 8
0.5 m
0.6 m
0.7 m
0.8 m
Impact Velocity (m/s)
Impact Angle (deg)
SNUM Sand
6
7
8.5
Penetration CG
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
SNUM Max Penetration CG
6 0.82 m
7 0.93 m
8.5 1.10 m
Min. impact velocity 217 m/s
Max. impact velocity 263 m/s
Min. impact angle 50 deg
Max. impact angle 79 deg


40mm MK2
Silt-Sand
Silt: Thickness 0.2 m, SNUM 10
0.6 m
0.7 m
0.8 m
Impact Velocity (m/s)
Impact Angle (deg)
SNUM Sand
6
7
8.5
Penetration CG
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
SNUM Max Penetration CG
6 0.87 m
7 0.98 m
8.5 1.14 m
Min. impact velocity 217 m/s
Max. impact velocity 263 m/s
Min. impact angle 50 deg
Max. impact angle 79 deg

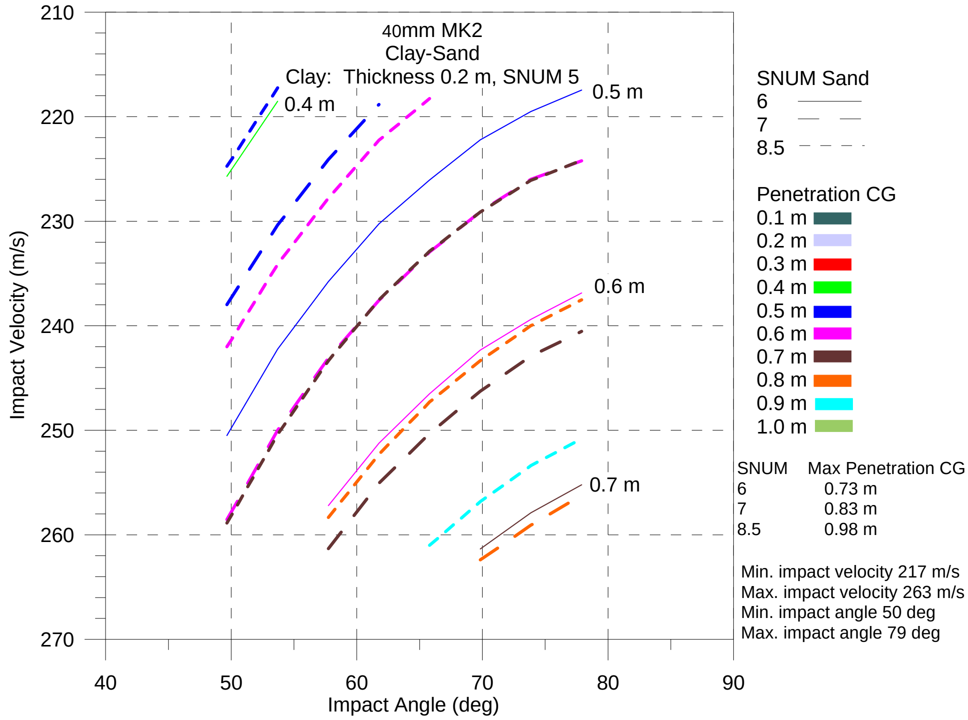
Silt-Clay


0.4 m
0.5 m
0.6 m
40mm MK2
Silt-Clay
Silt: Thickness 0.2 m, SNUM 5.5
Impact Velocity (m/s)
Impact Angle (deg)
SNUM Clay
5
9
12
Penetration CG
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
1.3 m
SNUM Max Penetration CG
5 0.66 m
9 1.06 m
12 1.37 m
Min. impact velocity 217 m/s
Max. impact velocity 263 m/s
Min. impact angle 50 deg
Max. impact angle 79 deg

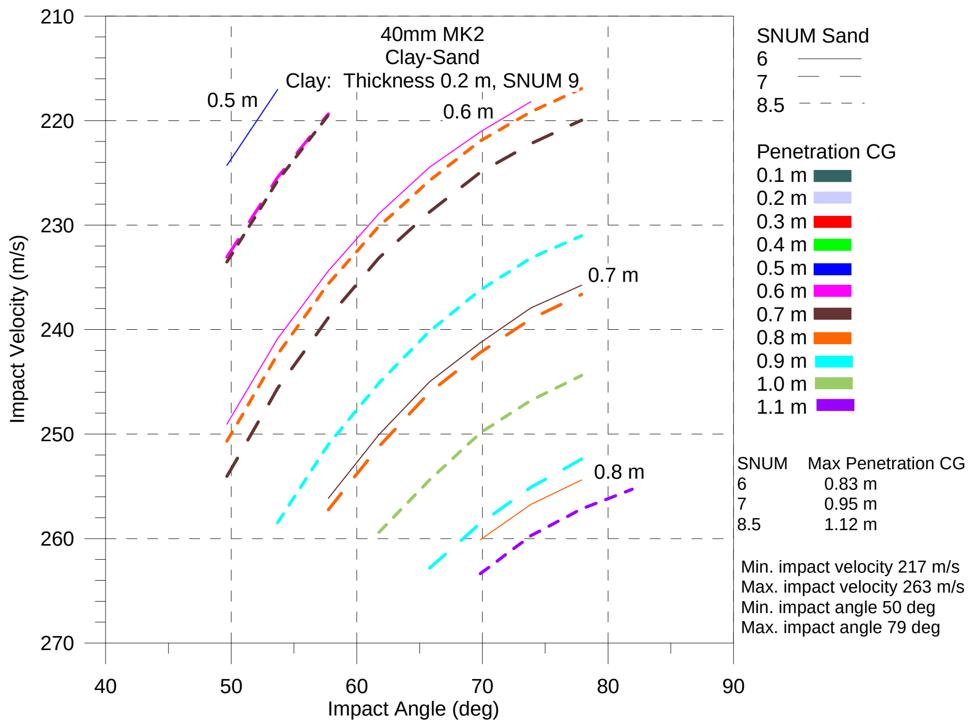

40mm MK2
Silt-Clay
Silt: Thickness 0.2 m, SNUM 8
0.5 m
0.6 m
0.7 m
0.1 m
0.2 m
0.3 m
0.4 m
Impact Velocity (m/s)
Impact Angle (deg)
SNUM Clay
5
9
12
Penetration CG
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
1.3 m
1.4 m
SNUM Max Penetration CG
5 0.70 m
9 1.16 m
12 1.50 m
Min. impact velocity 217 m/s
Max. impact velocity 263 m/s
Min. impact angle 50 deg
Max. impact angle 79 deg


40mm MK2
Silt-Clay
Silt: Thickness 0.2 m, SNUM 10
0.5 m
0.6 m
0.7 m
Impact Velocity (m/s)
Impact Angle (deg)
SNUM Clay
5
9
12
Penetration CG
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
1.3 m
1.4 m
1.5 m
SNUM Max Penetration CG
5 0.75 m
9 1.20 m
12 1.56 m
Min. impact velocity 217 m/s
Max. impact velocity 263 m/s
Min. impact angle 50 deg
Max. impact angle 79 deg

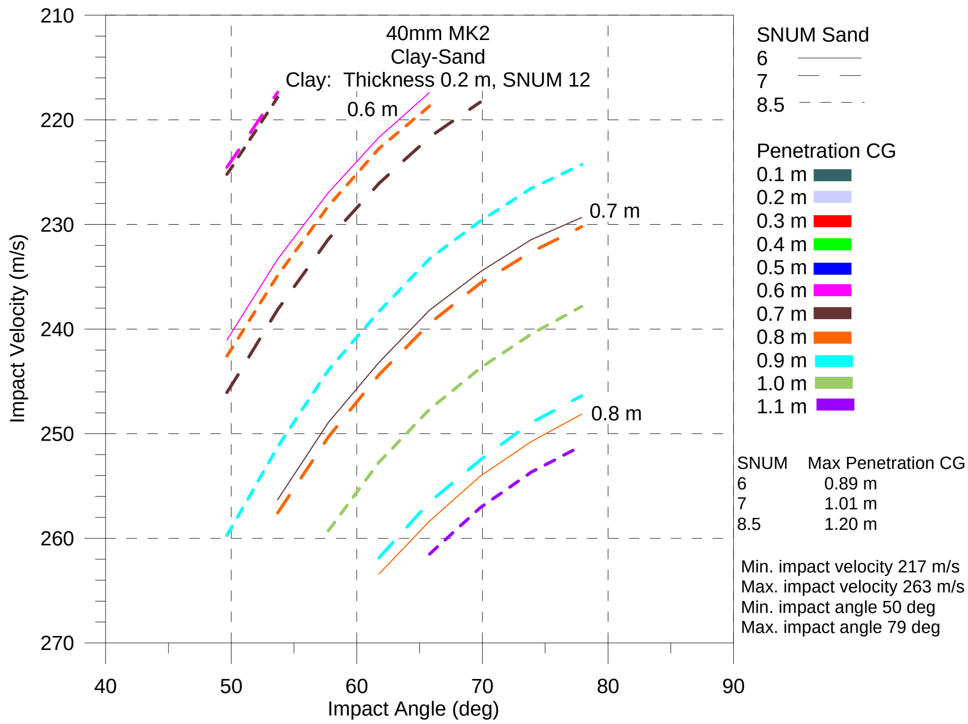
Clay-Sand



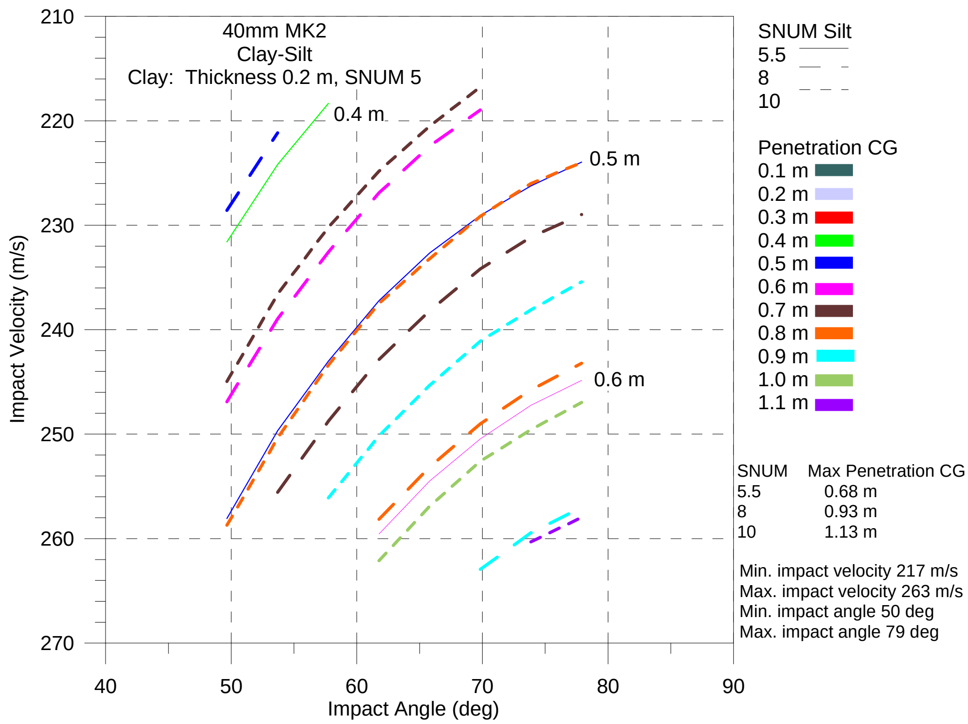
40mm MK2
Clay-Sand
Clay: Thickness 0.2 m, SNUM 5
0.4 m
0.5 m
0.6 m
0.7 m
Impact Velocity (m/s)
Impact Angle (deg)
SNUM Sand
6
7
8.5
Penetration CG
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
SNUM Max Penetration CG
6 0.73 m
7 0.83 m
8.5 0.98 m
Min. impact velocity 217 m/s
Max. impact velocity 263 m/s
Min. impact angle 50 deg
Max. impact angle 79 deg

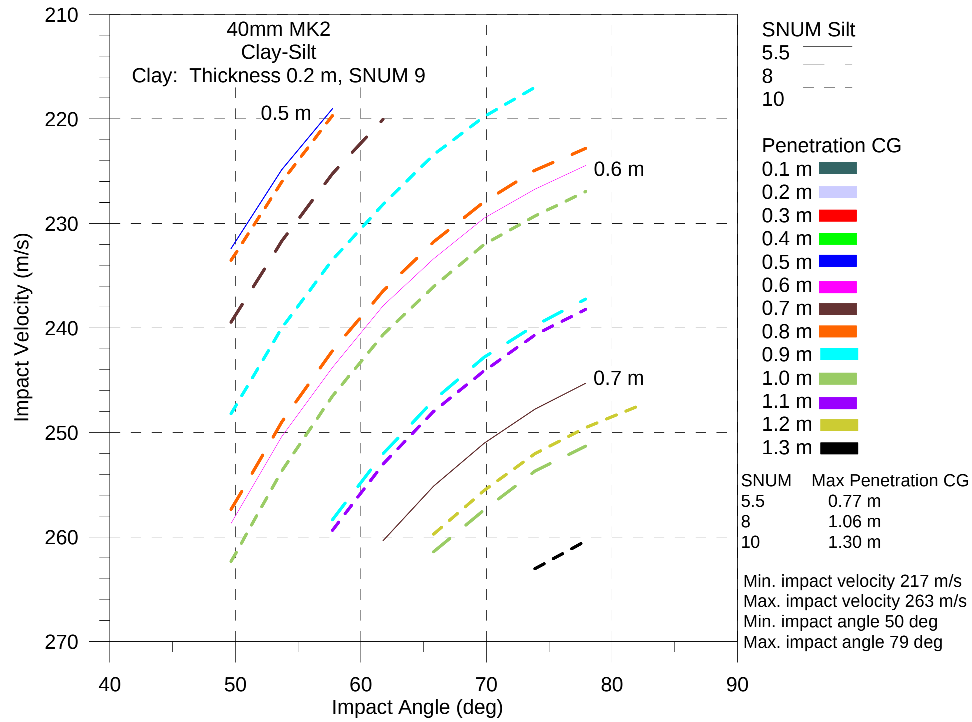


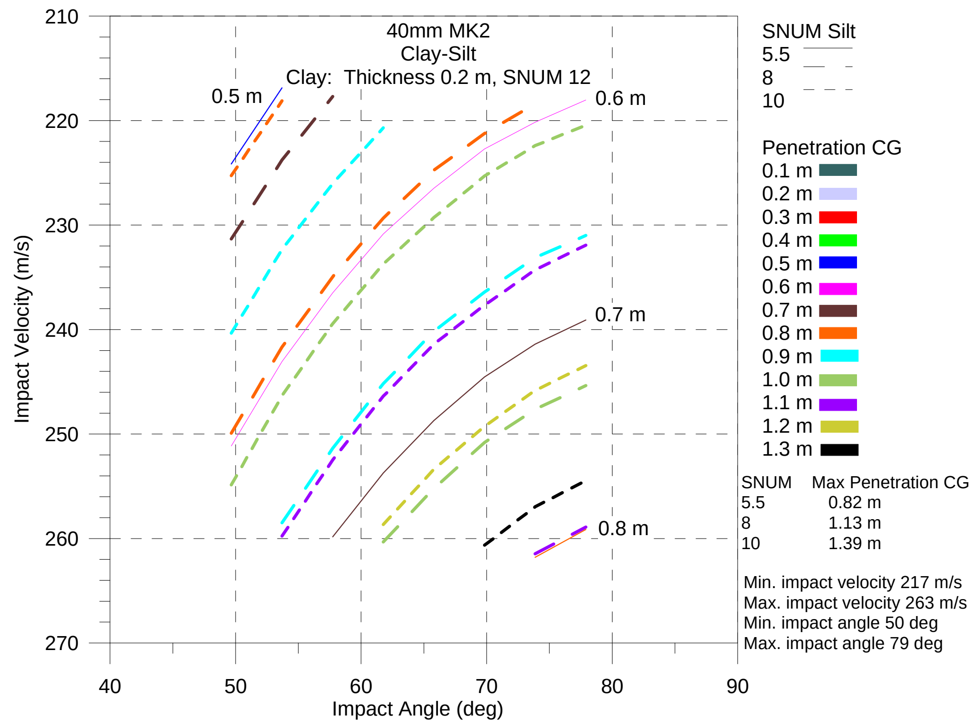
40mm MK2
Clay-Sand
Clay: Thickness 0.2 m, SNUM 9
0.5 m
0.6 m
0.7 m
0.8 m
Impact Velocity (m/s)
Impact Angle (deg)
SNUM Sand
6
7
8.5
Penetration CG
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
SNUM Max Penetration CG
6 0.83 m
7 0.95 m
8.5 1.12 m
Min. impact velocity 217 m/s
Max. impact velocity 263 m/s
Min. impact angle 50 deg
Max. impact angle 79 deg


40mm MK2
Clay-Sand
Clay: Thickness 0.2 m, SNUM 12
0.6 m
0.7 m
0.8 m
Impact Velocity (m/s)
Impact Angle (deg)
SNUM Sand
6
7
8.5
Penetration CG
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
SNUM Max Penetration CG
6 0.89 m
7 1.01 m
8.5 1.20 m
Min. impact velocity 217 m/s
Max. impact velocity 263 m/s
Min. impact angle 50 deg
Max. impact angle 79 deg

Clay-Silt

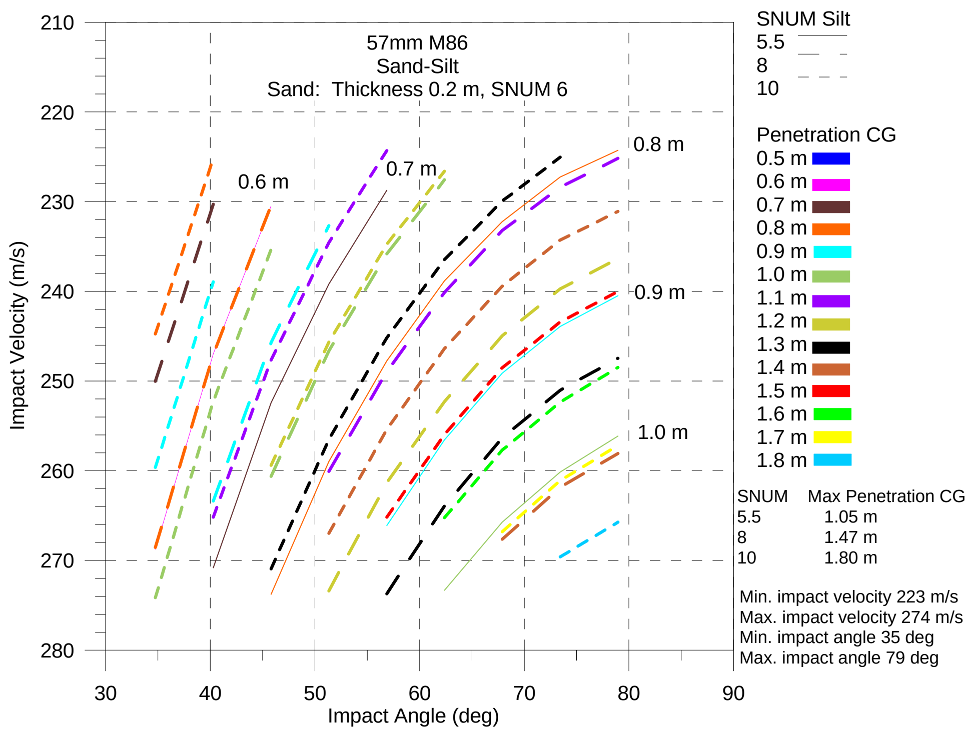

40mm MK2
Clay-Silt
Clay: Thickness 0.2 m, SNUM 5
0.4 m
0.5 m
0.6 m
Impact Velocity (m/s)
Impact Angle (deg)
SNUM Silt
5.5
8
10
Penetration CG
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
SNUM Max Penetration CG
5.5 0.68 m
8 0.93 m
10 1.13 m
Min. impact velocity 217 m/s
Max. impact velocity 263 m/s
Min. impact angle 50 deg
Max. impact angle 79 deg

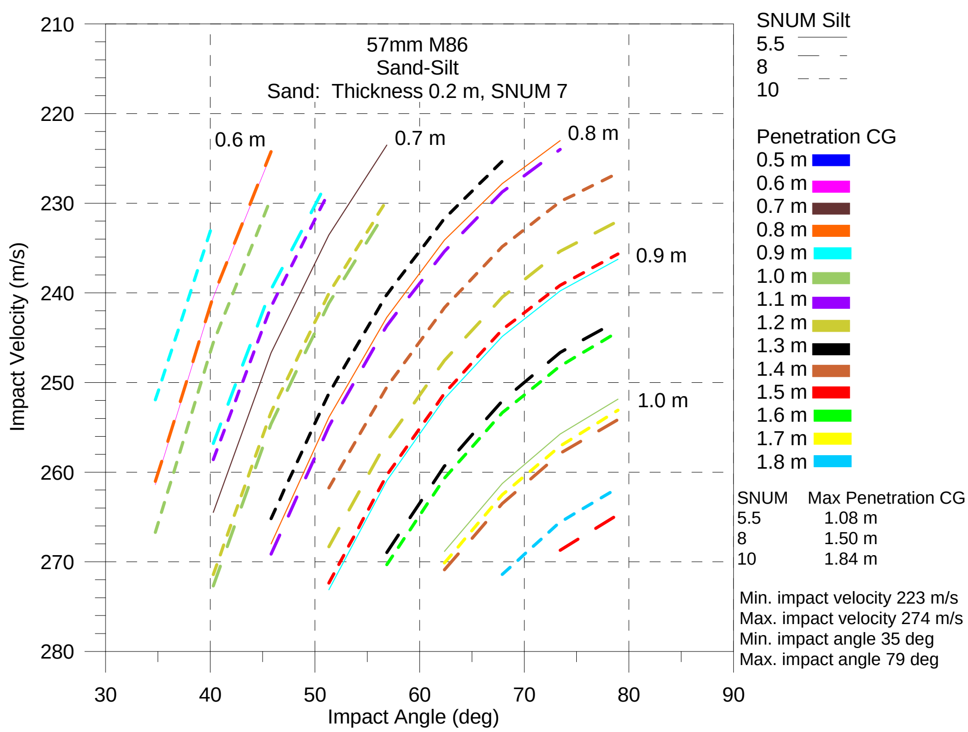

40mm MK2
Clay-Silt
Clay: Thickness 0.2 m, SNUM 9
0.5 m
0.6 m
0.7 m
Impact Velocity (m/s)
Impact Angle (deg)
SNUM Silt
5.5
8
10
Penetration CG
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
1.3 m
SNUM Max Penetration CG
5.5 0.77 m
8 1.06 m
10 1.30 m
Min. impact velocity 217 m/s
Max. impact velocity 263 m/s
Min. impact angle 50 deg
Max. impact angle 79 deg

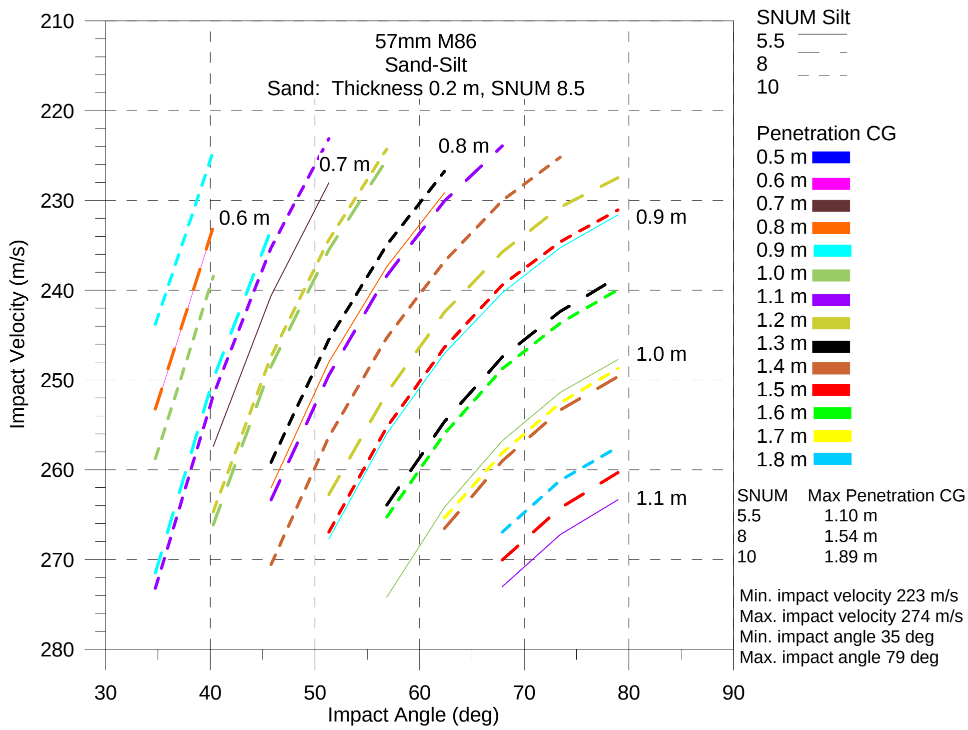

40mm MK2
Clay-Silt
Clay: Thickness 0.2 m, SNUM 12
0.5 m
0.6 m
0.7 m
0.8 m
Impact Velocity (m/s)
Impact Angle (deg)
SNUM Silt
5.5
8
10
Penetration CG
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
1.3 m
SNUM Max Penetration CG
5.5 0.82 m
8 1.13 m
10 1.39 m
Min. impact velocity 217 m/s
Max. impact velocity 263 m/s
Min. impact angle 50 deg
Max. impact angle 79 deg

57mm APC M86

Sand-Silt

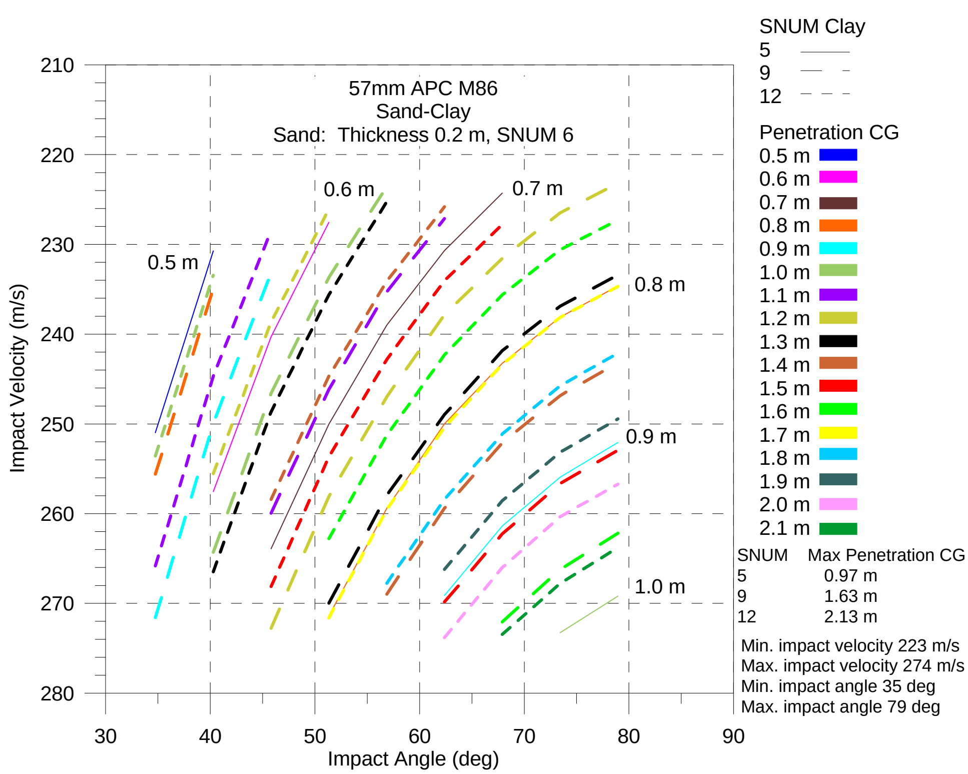




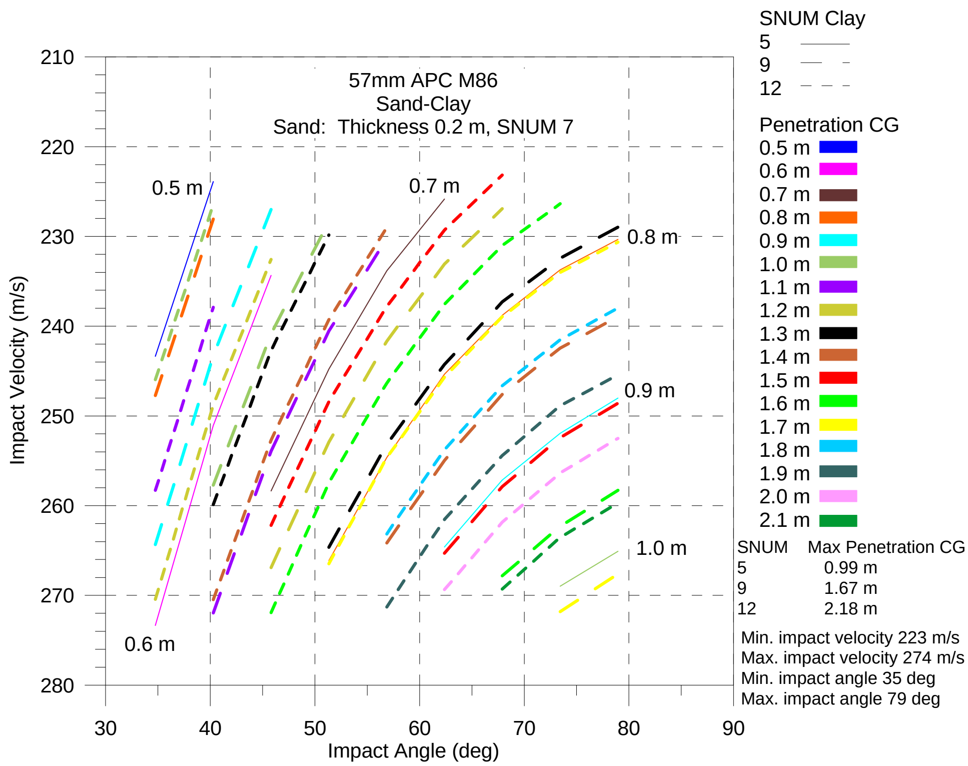


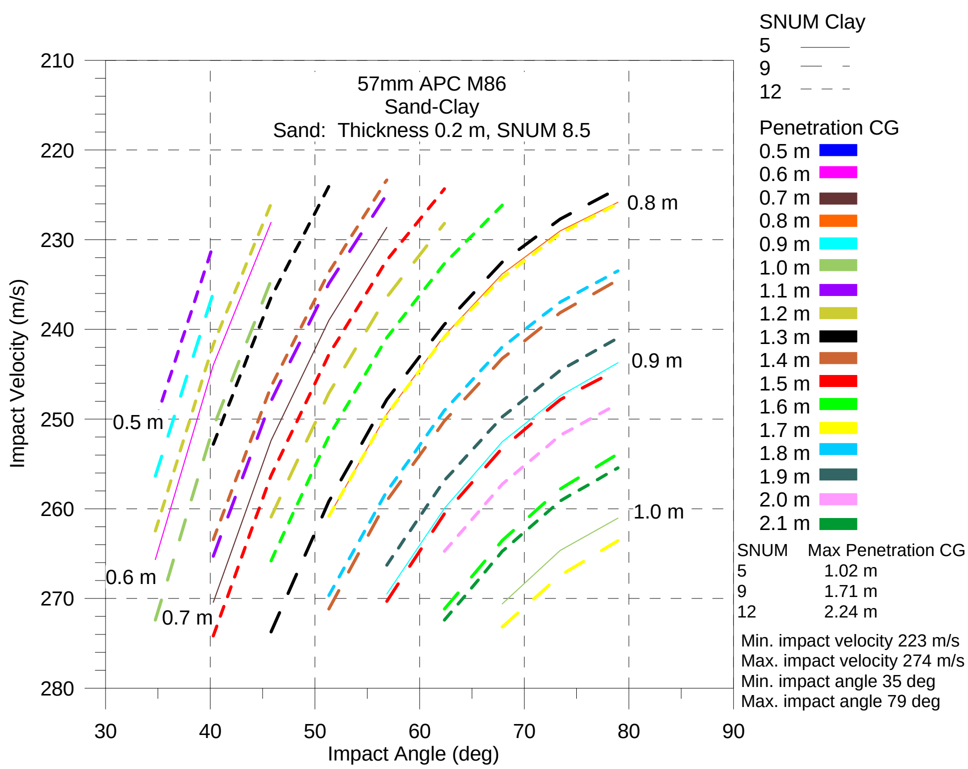
57mm M86
Sand-Silt
Sand: Thickness 0.2 m, SNUM 8.5
SNUM Silt
5.5
8
10
Penetration CG
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
1.3 m
1.4 m
1.5 m
1.6 m
1.7 m
1.8 m
SNUM Max Penetration CG
5.5 1.10 m
8 1.54 m
10 1.89 m
Min. impact velocity 223 m/s
Max. impact velocity 274 m/s
Min. impact angle 35 deg
Max. impact angle 79 deg
Impact Velocity (m/s)
Impact Angle (deg)

Sand-Clay

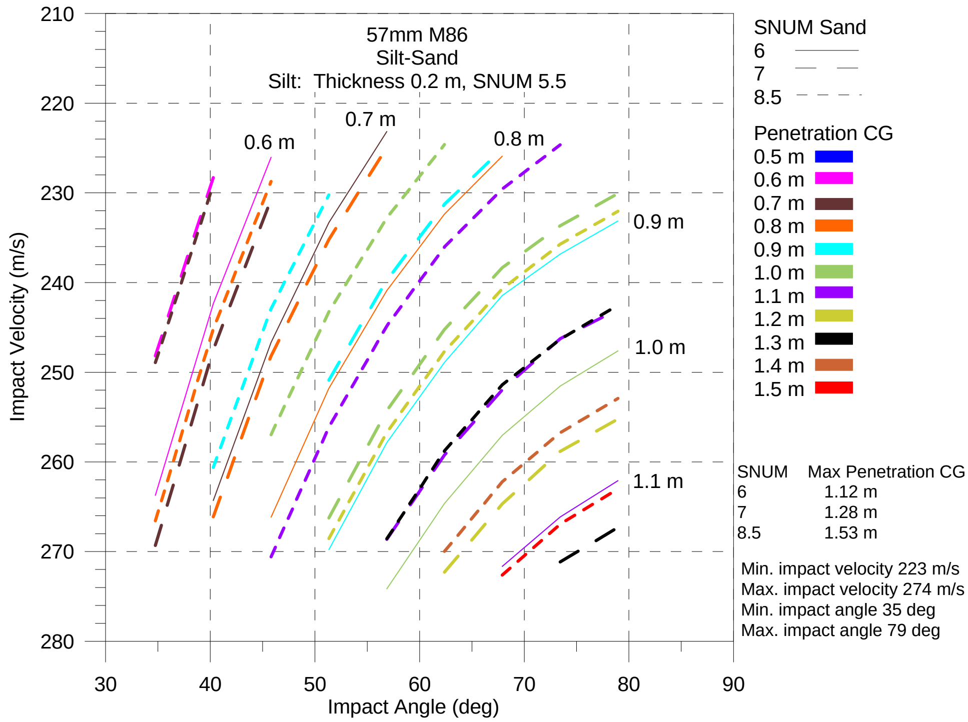


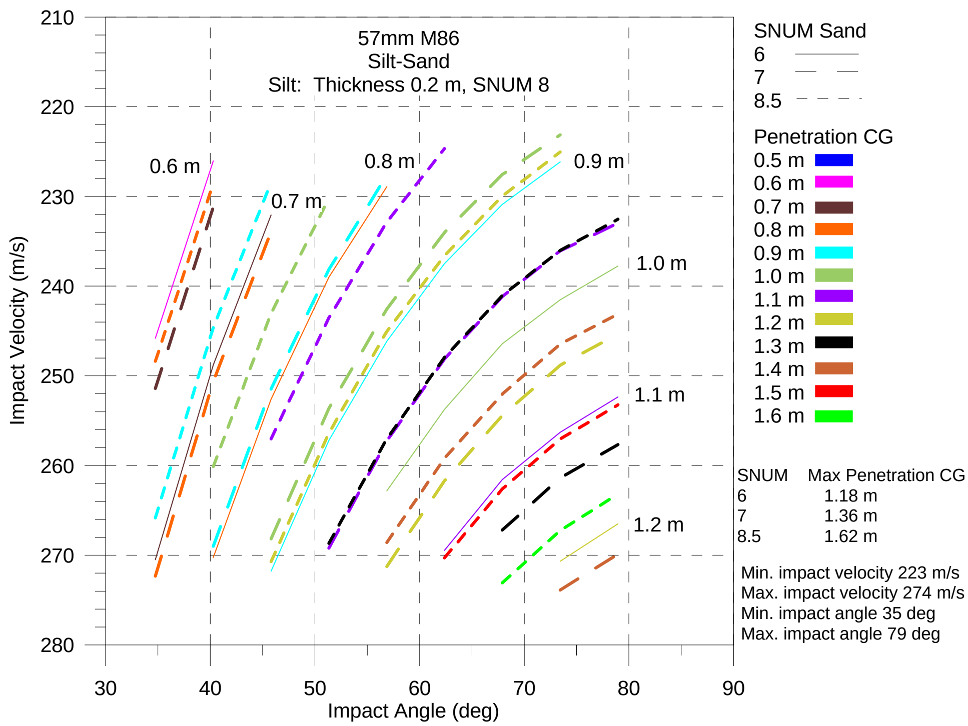
57mm APC M86
Sand-Clay
Sand: Thickness 0.2 m, SNUM 6
SNUM Clay
5
9
12
Penetration CG
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
1.3 m
1.4 m
1.5 m
1.6 m
1.7 m
1.8 m
1.9 m
2.0 m
2.1 m
SNUM Max Penetration CG
5 0.97 m
9 1.63 m
12 2.13 m
Min. impact velocity 223 m/s
Max. impact velocity 274 m/s
Min. impact angle 35 deg
Max. impact angle 79 deg
Impact Velocity (m/s)
Impact Angle (deg)

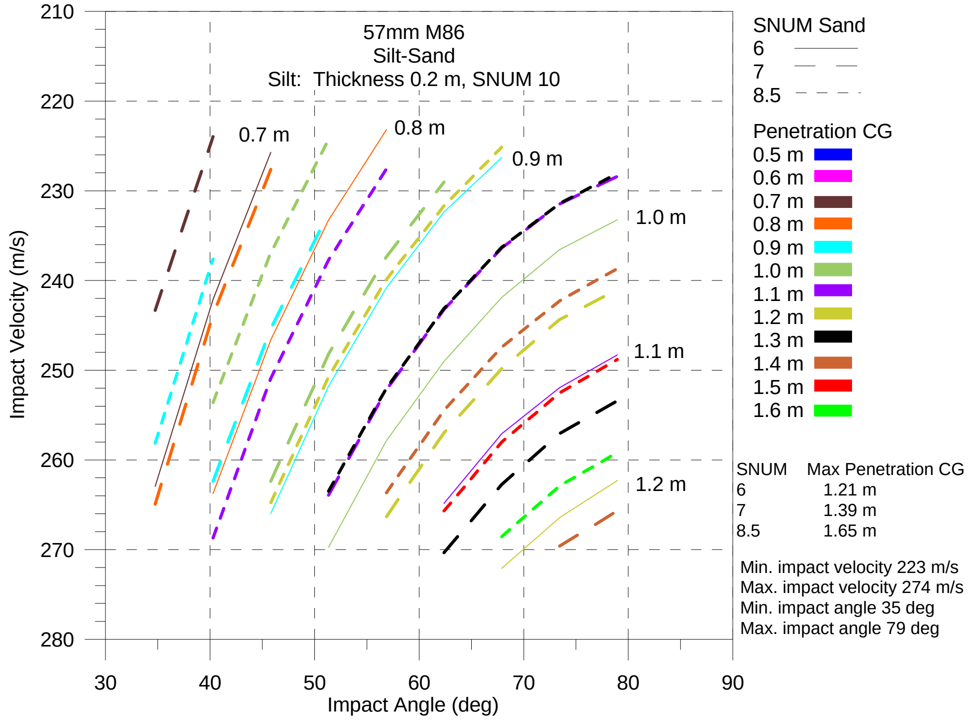

57mm APC M86
Sand-Clay
Sand: Thickness 0.2 m, SNUM 7
Impact Velocity (m/s)
Impact Angle (deg)
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
SNUM Clay
5
9
12
Penetration CG
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
1.3 m
1.4 m
1.5 m
1.6 m
1.7 m
1.8 m
1.9 m
2.0 m
2.1 m
SNUM Max Penetration CG
5 0.99 m
9 1.67 m
12 2.18 m
Min. impact velocity 223 m/s
Max. impact velocity 274 m/s
Min. impact angle 35 deg
Max. impact angle 79 deg


57mm APC M86
Sand-Clay
Sand: Thickness 0.2 m, SNUM 8.5
Impact Velocity (m/s)
Impact Angle (deg)
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
SNUM Clay
5
9
12
Penetration CG
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
1.3 m
1.4 m
1.5 m
1.6 m
1.7 m
1.8 m
1.9 m
2.0 m
2.1 m
SNUM Max Penetration CG
5 1.02 m
9 1.71 m
12 2.24 m
Min. impact velocity 223 m/s
Max. impact velocity 274 m/s
Min. impact angle 35 deg
Max. impact angle 79 deg

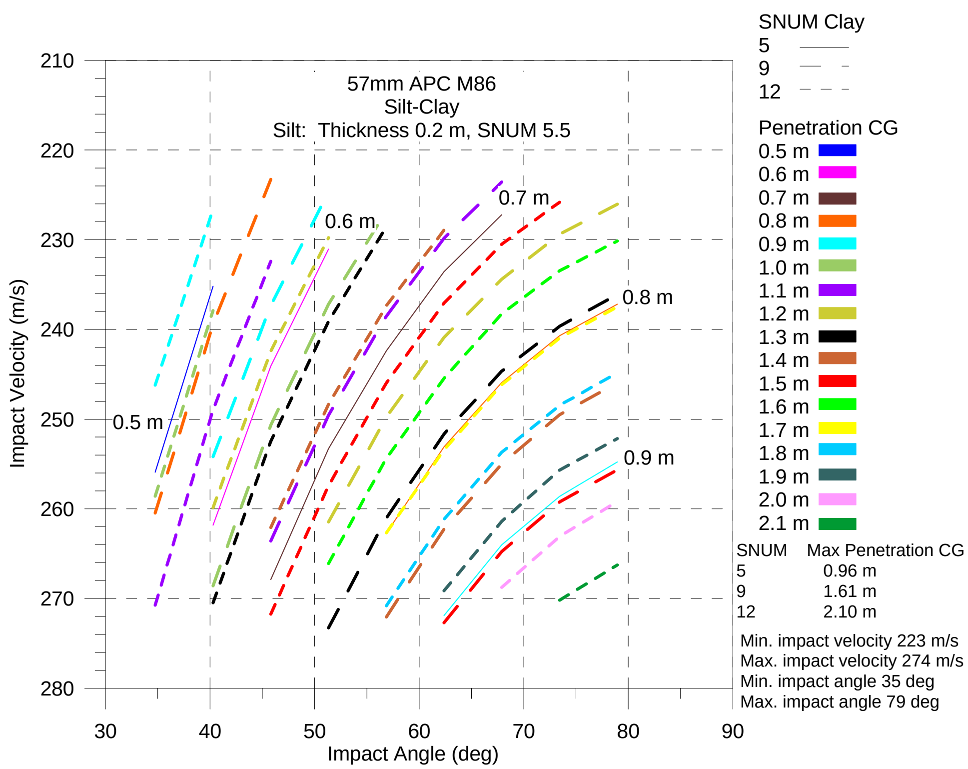
Silt-Sand

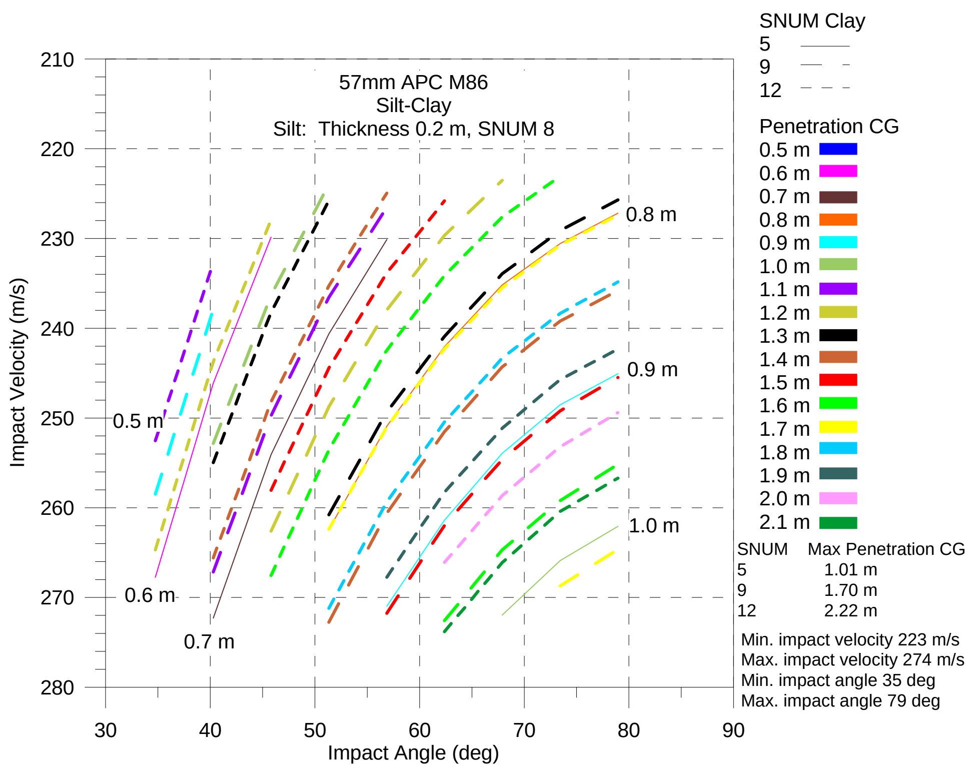

57mm M86
Silt-Sand
Silt: Thickness 0.2 m, SNUM 5.5
SNUM Sand
6
7
8.5
Penetration CG
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
1.3 m
1.4 m
1.5 m
SNUM Max Penetration CG
6 1.12 m
7 1.28 m
8.5 1.53 m
Min. impact velocity 223 m/s
Max. impact velocity 274 m/s
Min. impact angle 35 deg
Max. impact angle 79 deg
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
Impact Velocity (m/s)
Impact Angle (deg)

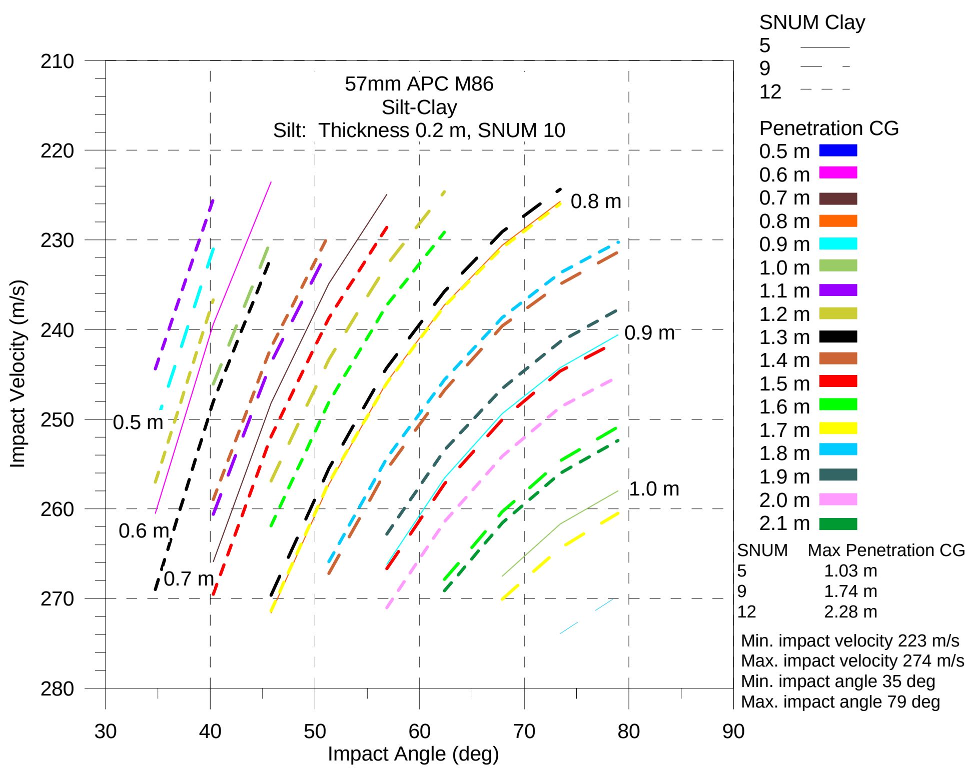

57mm M86
Silt-Sand
Silt: Thickness 0.2 m, SNUM 8
SNUM Sand
6
7
8.5
Penetration CG
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
1.3 m
1.4 m
1.5 m
1.6 m
SNUM Max Penetration CG
6 1.18 m
7 1.36 m
8.5 1.62 m
Min. impact velocity 223 m/s
Max. impact velocity 274 m/s
Min. impact angle 35 deg
Max. impact angle 79 deg
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
Impact Velocity (m/s)
Impact Angle (deg)


57mm M86
Silt-Sand
Silt: Thickness 0.2 m, SNUM 10
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
Impact Velocity (m/s)
Impact Angle (deg)
SNUM Sand
6
7
8.5
Penetration CG
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
1.3 m
1.4 m
1.5 m
1.6 m
SNUM Max Penetration CG
6 1.21 m
7 1.39 m
8.5 1.65 m
Min. impact velocity 223 m/s
Max. impact velocity 274 m/s
Min. impact angle 35 deg
Max. impact angle 79 deg

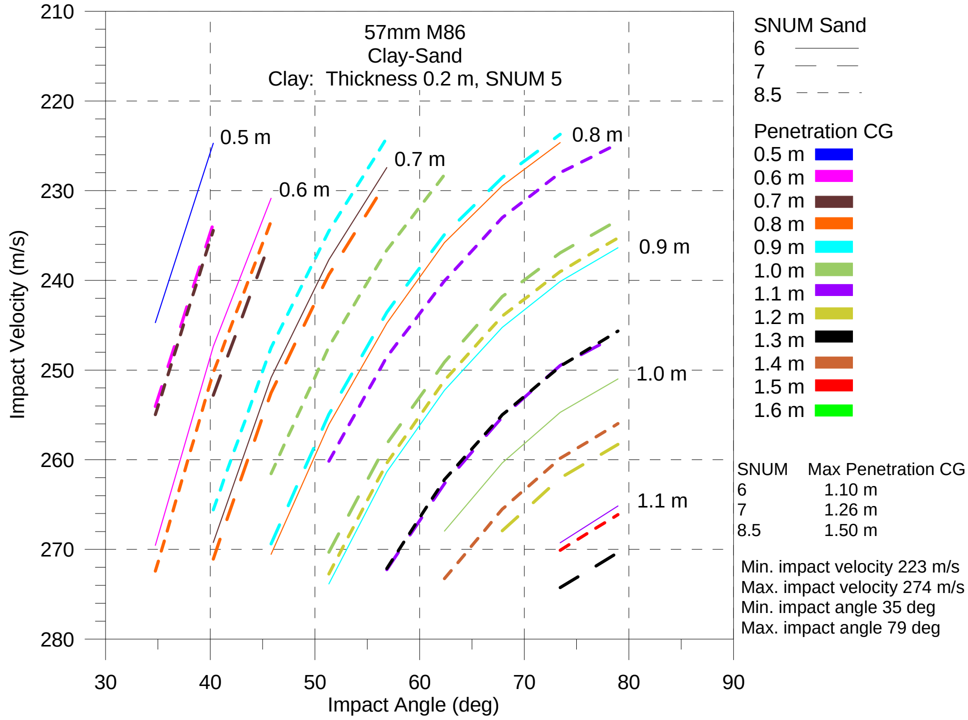
Silt-Clay

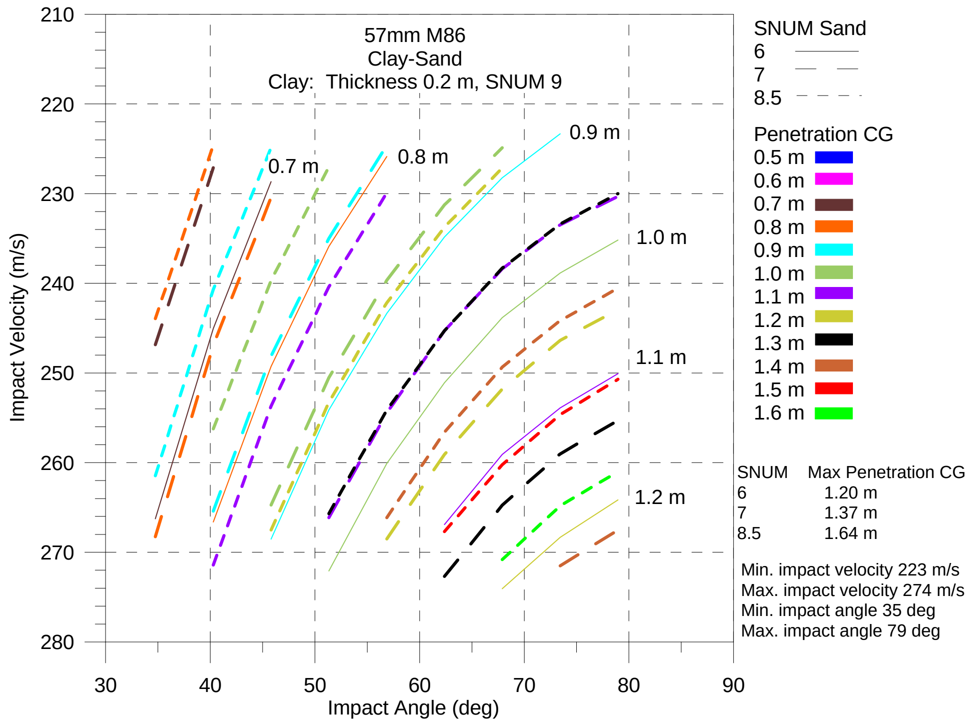

57mm APC M86
Silt-Clay
Silt: Thickness 0.2 m, SNUM 5.5
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
Impact Velocity (m/s)
Impact Angle (deg)
SNUM Clay
5
9
12
Penetration CG
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
1.3 m
1.4 m
1.5 m
1.6 m
1.7 m
1.8 m
1.9 m
2.0 m
2.1 m
SNUM Max Penetration CG
5 0.96 m
9 1.61 m
12 2.10 m
Min. impact velocity 223 m/s
Max. impact velocity 274 m/s
Min. impact angle 35 deg
Max. impact angle 79 deg

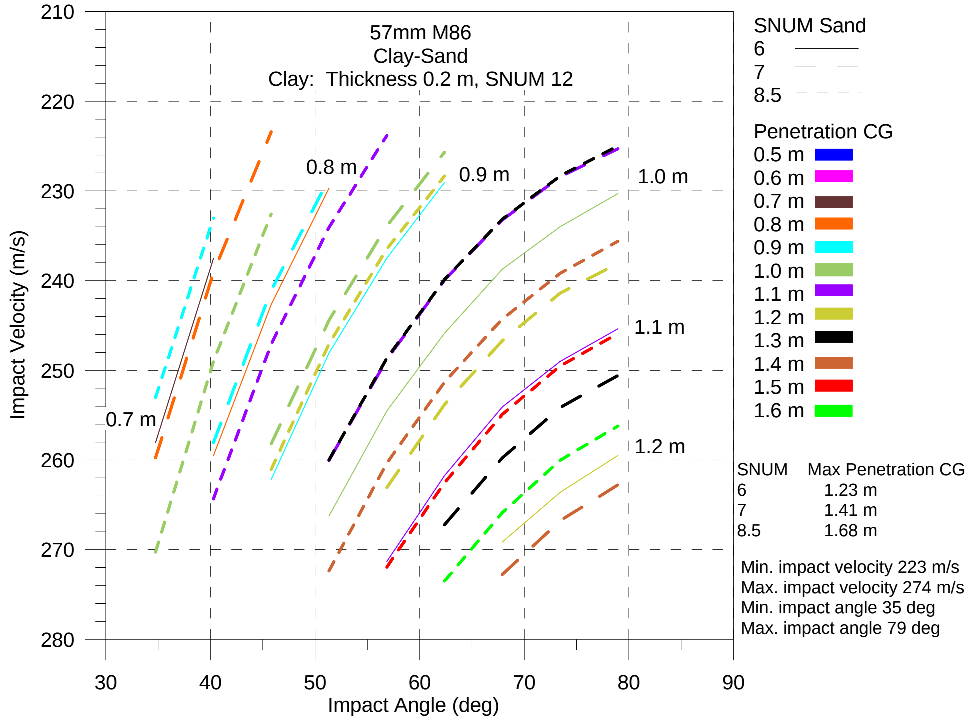

57mm APC M86
Silt-Clay
Silt: Thickness 0.2 m, SNUM 8
Impact Velocity (m/s)
Impact Angle (deg)
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
SNUM Clay
5
9
12
Penetration CG
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
1.3 m
1.4 m
1.5 m
1.6 m
1.7 m
1.8 m
1.9 m
2.0 m
2.1 m
SNUM Max Penetration CG
5 1.01 m
9 1.70 m
12 2.22 m
Min. impact velocity 223 m/s
Max. impact velocity 274 m/s
Min. impact angle 35 deg
Max. impact angle 79 deg


57mm APC M86
Silt-Clay
Silt: Thickness 0.2 m, SNUM 10
Impact Velocity (m/s)
Impact Angle (deg)
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
SNUM Clay
5
9
12
Penetration CG
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
1.3 m
1.4 m
1.5 m
1.6 m
1.7 m
1.8 m
1.9 m
2.0 m
2.1 m
SNUM Max Penetration CG
5 1.03 m
9 1.74 m
12 2.28 m
Min. impact velocity 223 m/s
Max. impact velocity 274 m/s
Min. impact angle 35 deg
Max. impact angle 79 deg

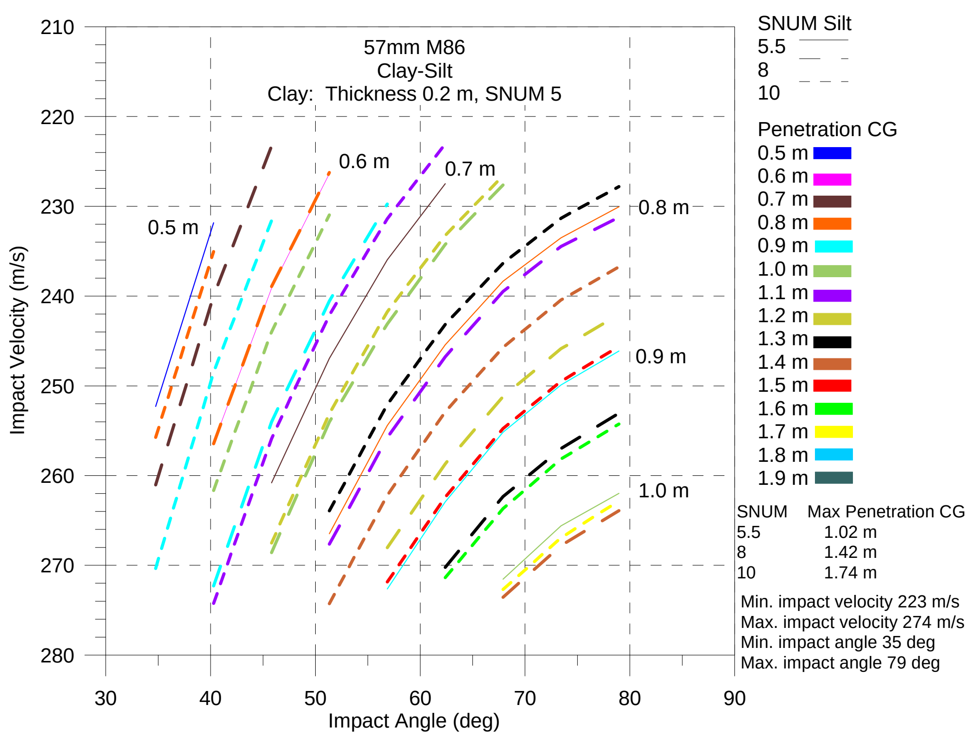
Clay-Sand

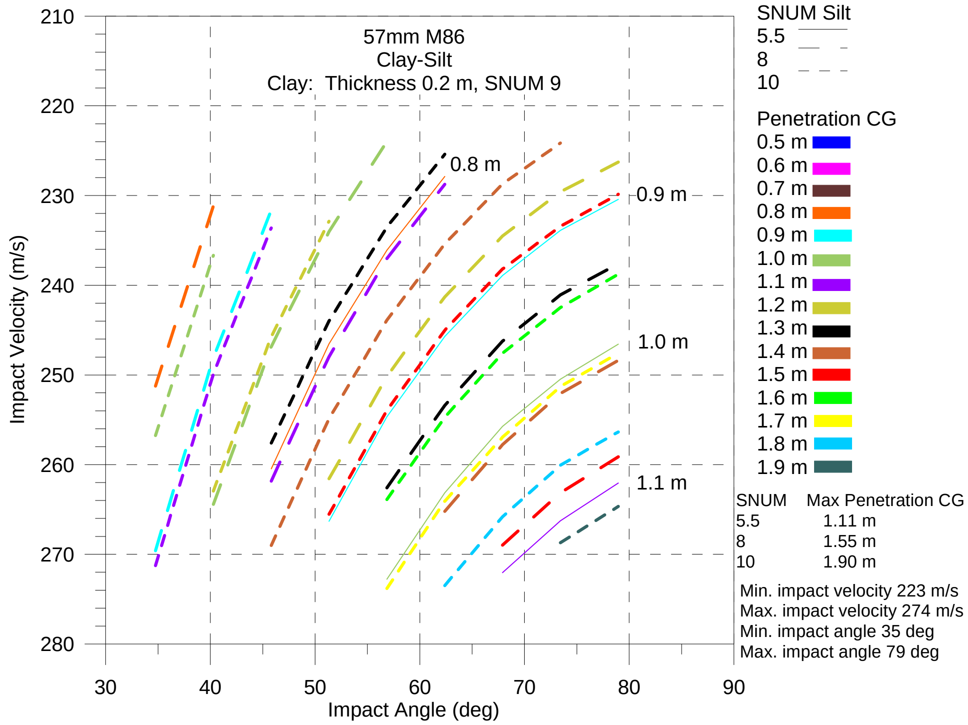

57mm M86
Clay-Sand
Clay: Thickness 0.2 m, SNUM 5
Impact Velocity (m/s)
Impact Angle (deg)
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
SNUM Sand
6
7
8.5
Penetration CG
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
1.3 m
1.4 m
1.5 m
1.6 m
SNUM Max Penetration CG
6 1.10 m
7 1.26 m
8.5 1.50 m
Min. impact velocity 223 m/s
Max. impact velocity 274 m/s
Min. impact angle 35 deg
Max. impact angle 79 deg


57mm M86
Clay-Sand
Clay: Thickness 0.2 m, SNUM 9
Impact Velocity (m/s)
Impact Angle (deg)
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
SNUM Sand
6
7
8.5
Penetration CG
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
1.3 m
1.4 m
1.5 m
1.6 m
SNUM Max Penetration CG
6 1.20 m
7 1.37 m
8.5 1.64 m
Min. impact velocity 223 m/s
Max. impact velocity 274 m/s
Min. impact angle 35 deg
Max. impact angle 79 deg

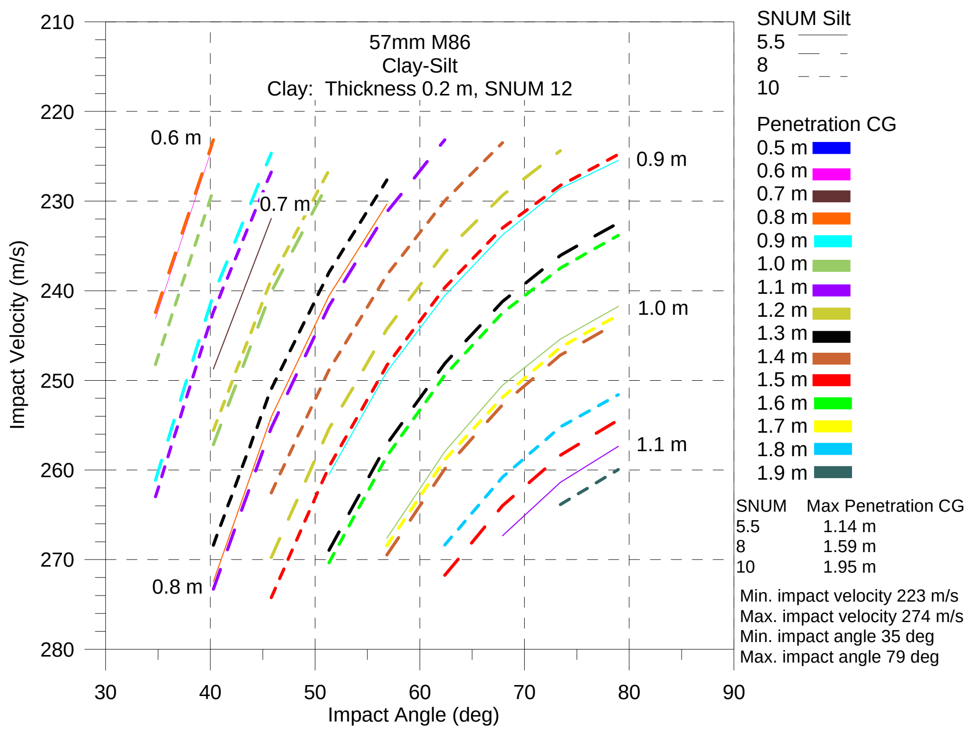

57mm M86
Clay-Sand
Clay: Thickness 0.2 m, SNUM 12
Impact Velocity (m/s)
Impact Angle (deg)
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
SNUM Sand
6
7
8.5
Penetration CG
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
1.3 m
1.4 m
1.5 m
1.6 m
SNUM Max Penetration CG
6 1.23 m
7 1.41 m
8.5 1.68 m
Min. impact velocity 223 m/s
Max. impact velocity 274 m/s
Min. impact angle 35 deg
Max. impact angle 79 deg

Clay-Silt


57mm M86
Clay-Silt
Clay: Thickness 0.2 m, SNUM 5
Impact Velocity (m/s)
Impact Angle (deg)
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
SNUM Silt
5.5
8
10
Penetration CG
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
1.3 m
1.4 m
1.5 m
1.6 m
1.7 m
1.8 m
1.9 m
SNUM Max Penetration CG
5.5 1.02 m
8 1.42 m
10 1.74 m
Min. impact velocity 223 m/s
Max. impact velocity 274 m/s
Min. impact angle 35 deg
Max. impact angle 79 deg



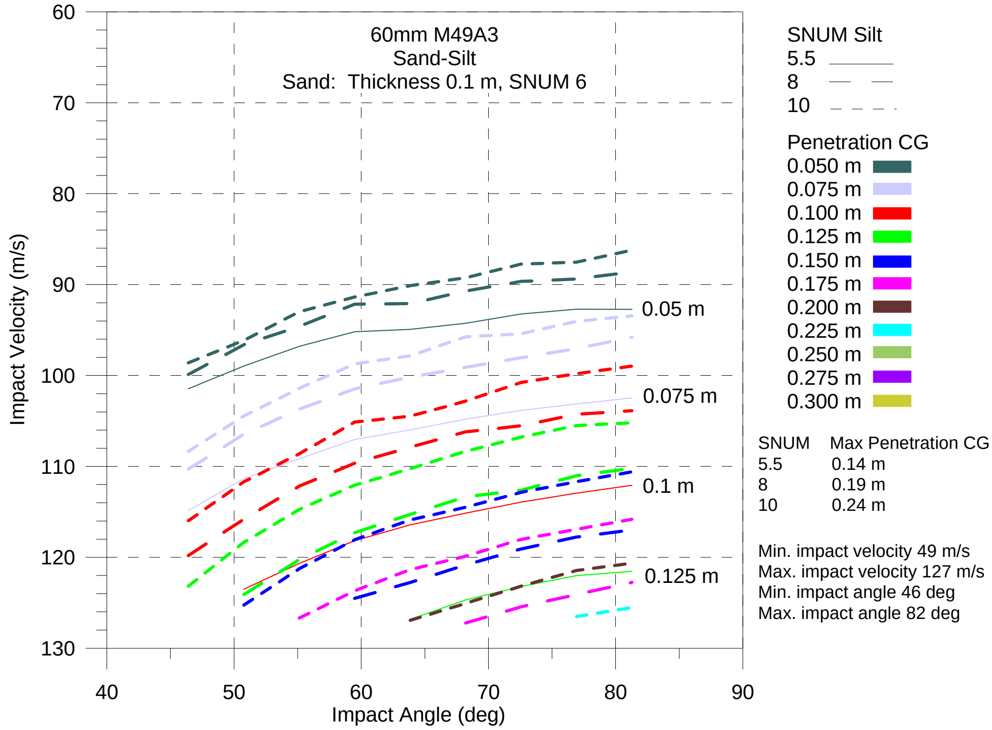
57mm M86
Clay-Silt
Clay: Thickness 0.2 m, SNUM 9
Impact Velocity (m/s)
Impact Angle (deg)
0.8 m
0.9 m
1.0 m
1.1 m
SNUM Silt
5.5
8
10
Penetration CG
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
1.3 m
1.4 m
1.5 m
1.6 m
1.7 m
1.8 m
1.9 m
SNUM Max Penetration CG
5.5 1.11 m
8 1.55 m
10 1.90 m
Min. impact velocity 223 m/s
Max. impact velocity 274 m/s
Min. impact angle 35 deg
Max. impact angle 79 deg

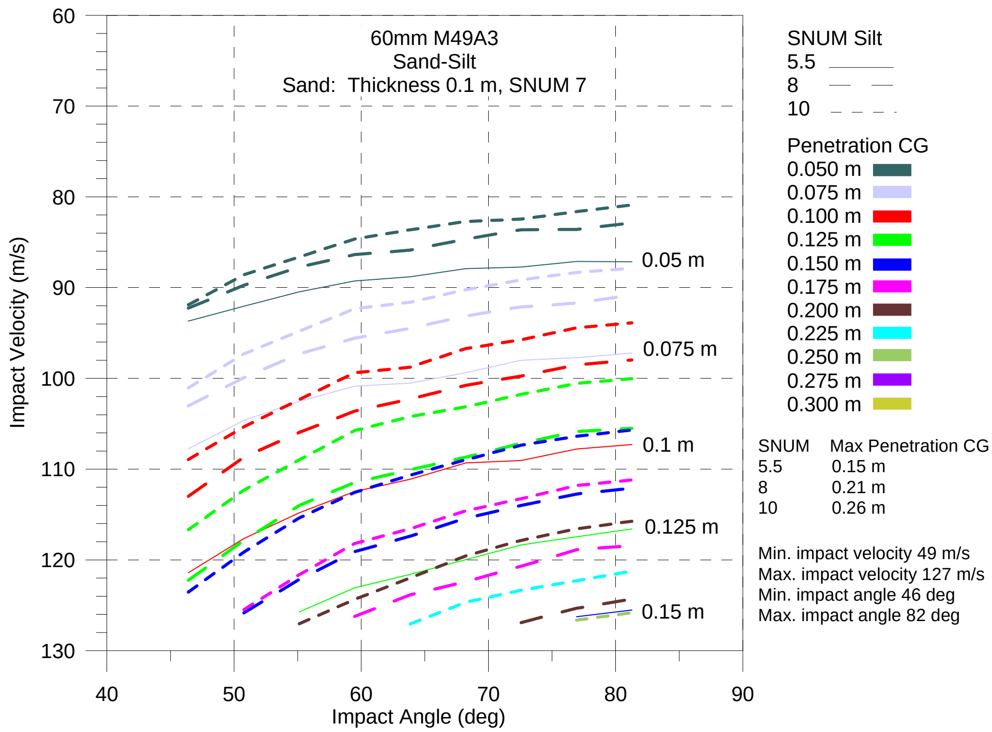


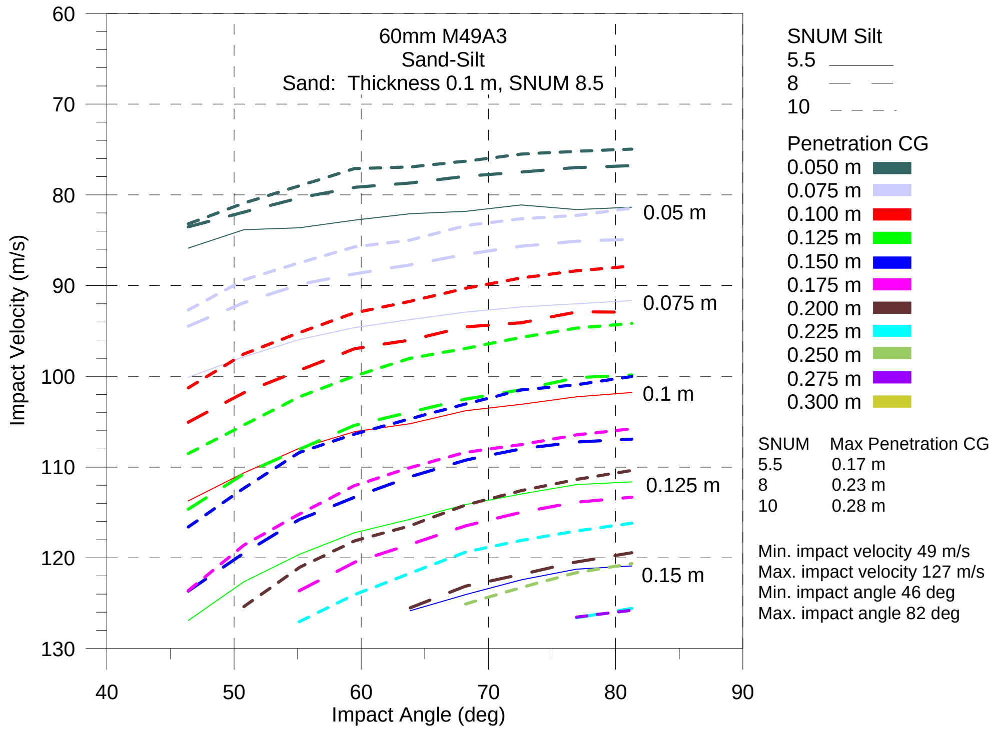
57mm M86
Clay-Silt
Clay: Thickness 0.2 m, SNUM 12
Impact Velocity (m/s)
Impact Angle (deg)
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
SNUM Silt
5.5
8
10
Penetration CG
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
1.3 m
1.4 m
1.5 m
1.6 m
1.7 m
1.8 m
1.9 m
SNUM Max Penetration CG
5.5 1.14 m
8 1.59 m
10 1.95 m
Min. impact velocity 223 m/s
Max. impact velocity 274 m/s
Min. impact angle 35 deg
Max. impact angle 79 deg

60mm M49A3

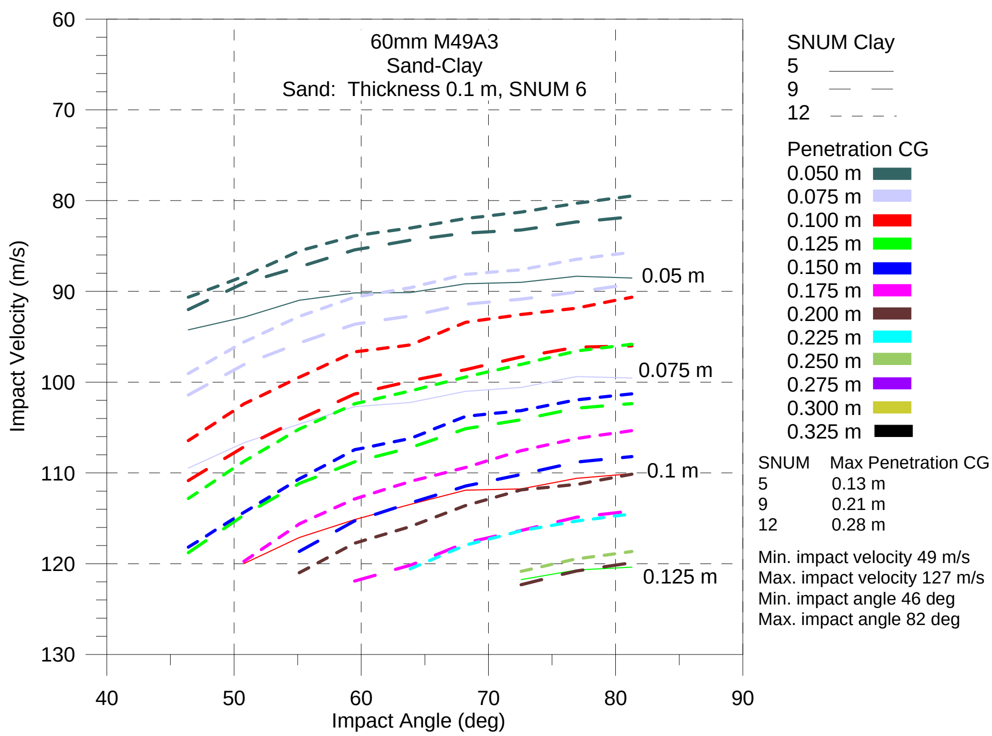
Sand-Silt

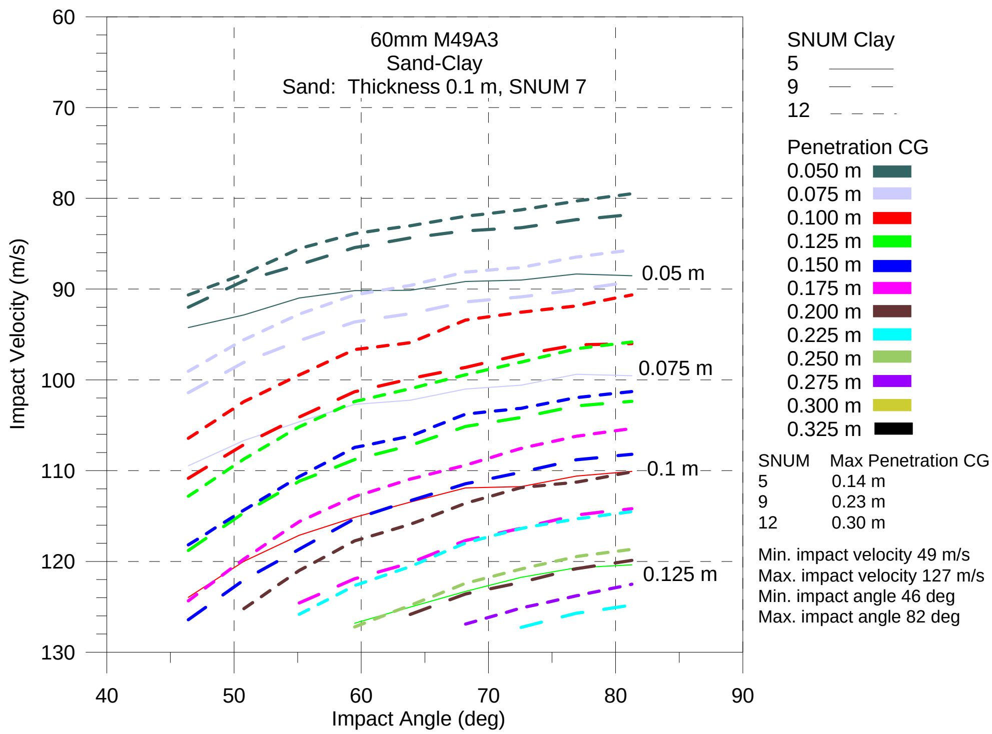




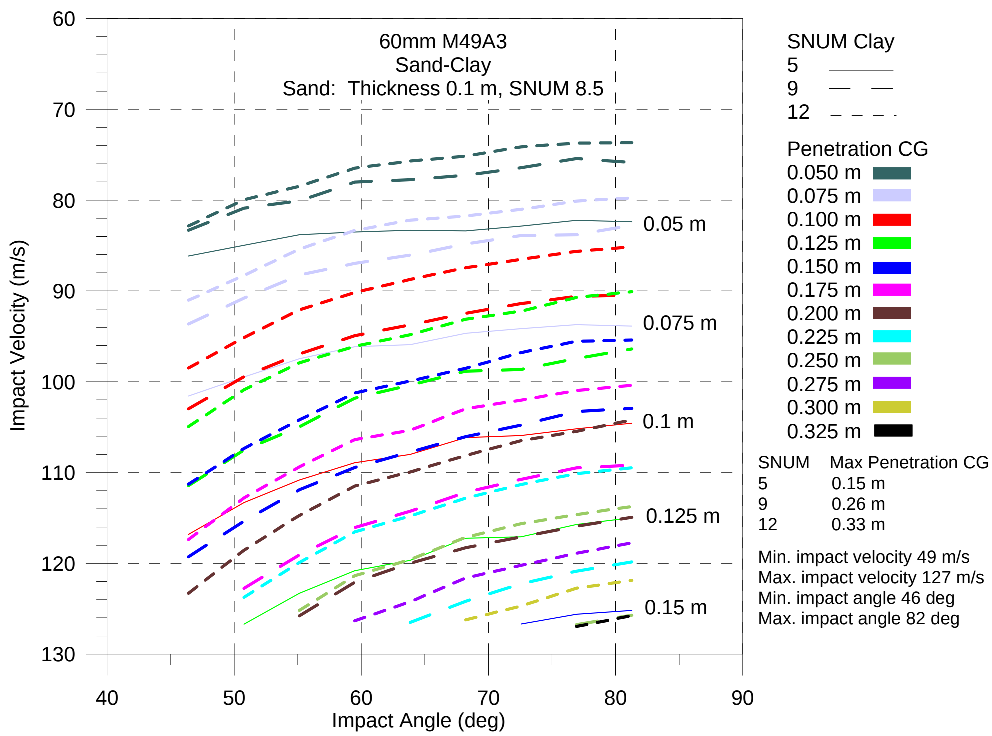

60mm M49A3
Sand-Silt
Sand: Thickness 0.1 m, SNUM 8.5
0.05 m
0.075 m
0.1 m
0.125 m
0.15 m
Impact Velocity (m/s)
Impact Angle (deg)
SNUM Silt
5.5
8
10
Penetration CG
0.050 m
0.075 m
0.100 m
0.125 m
0.150 m
0.175 m
0.200 m
0.225 m
0.250 m
0.275 m
0.300 m
SNUM Max Penetration CG
5.5 0.17 m
8 0.23 m
10 0.28 m
Min. impact velocity 49 m/s
Max. impact velocity 127 m/s
Min. impact angle 46 deg
Max. impact angle 82 deg

Sand-Clay


60mm M49A3
Sand-Clay
Sand: Thickness 0.1 m, SNUM 6
0.05 m
0.075 m
0.1 m
0.125 m
Impact Velocity (m/s)
Impact Angle (deg)
SNUM Clay
5
9
12
Penetration CG
0.050 m
0.075 m
0.100 m
0.125 m
0.150 m
0.175 m
0.200 m
0.225 m
0.250 m
0.275 m
0.300 m
0.325 m
SNUM Max Penetration CG
5 0.13 m
9 0.21 m
12 0.28 m
Min. impact velocity 49 m/s
Max. impact velocity 127 m/s
Min. impact angle 46 deg
Max. impact angle 82 deg

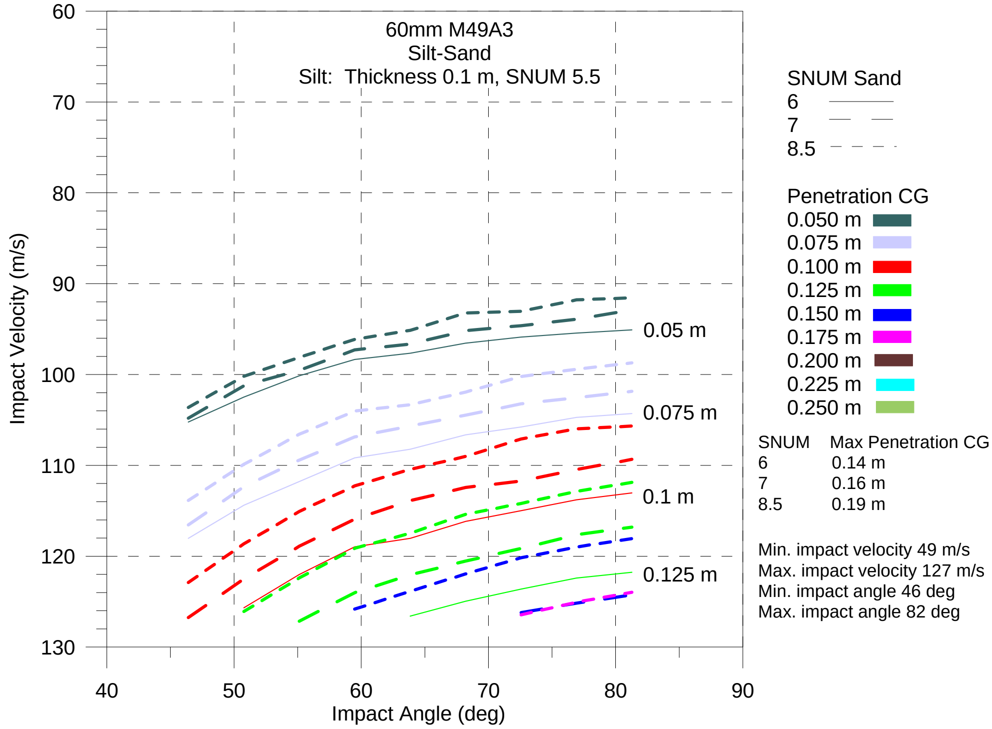


60mm M49A3
Sand-Clay
Sand: Thickness 0.1 m, SNUM 7
Impact Velocity (m/s)
Impact Angle (deg)
0.05 m
0.075 m
0.1 m
0.125 m
SNUM Clay
5
9
12
Penetration CG
0.050 m
0.075 m
0.100 m
0.125 m
0.150 m
0.175 m
0.200 m
0.225 m
0.250 m
0.275 m
0.300 m
0.325 m
SNUM Max Penetration CG
5 0.14 m
9 0.23 m
12 0.30 m
Min. impact velocity 49 m/s
Max. impact velocity 127 m/s
Min. impact angle 46 deg
Max. impact angle 82 deg

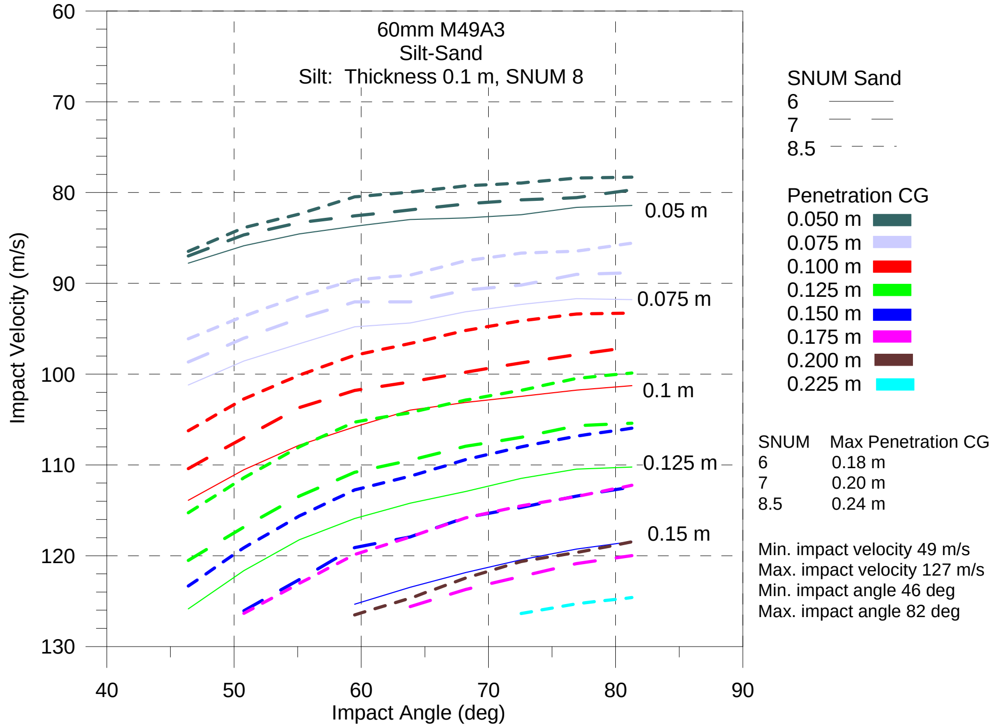


60mm M49A3
Sand-Clay
Sand: Thickness 0.1 m, SNUM 8.5
Impact Velocity (m/s)
Impact Angle (deg)
0.05 m
0.075 m
0.1 m
0.125 m
0.15 m
SNUM Clay
5
9
12
Penetration CG
0.050 m
0.075 m
0.100 m
0.125 m
0.150 m
0.175 m
0.200 m
0.225 m
0.250 m
0.275 m
0.300 m
0.325 m
SNUM Max Penetration CG
5 0.15 m
9 0.26 m
12 0.33 m
Min. impact velocity 49 m/s
Max. impact velocity 127 m/s
Min. impact angle 46 deg
Max. impact angle 82 deg

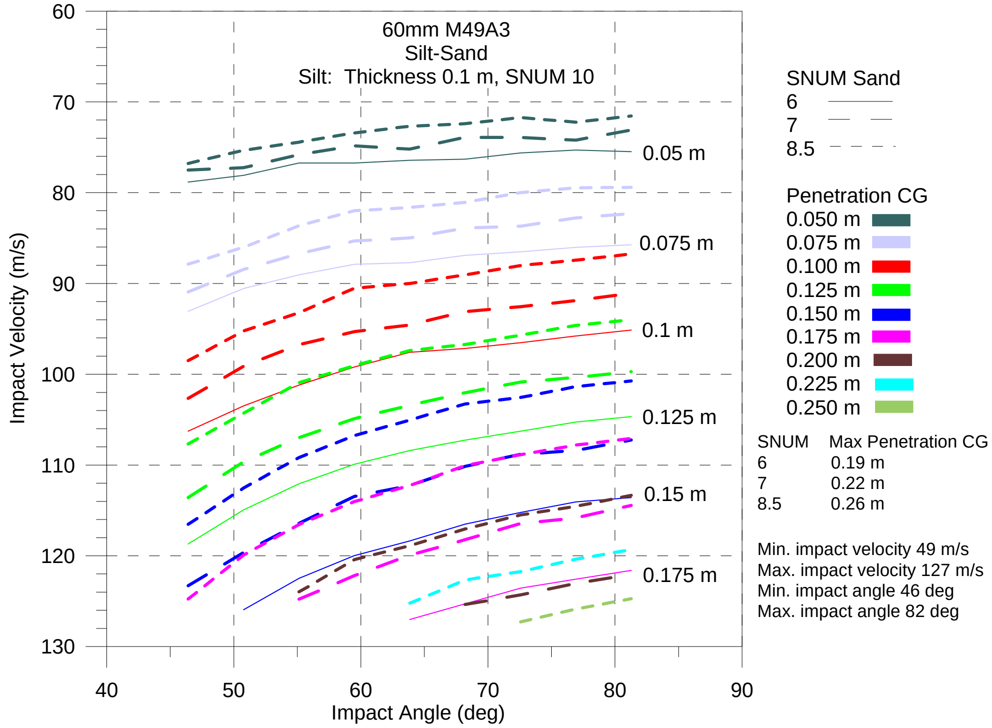
Silt-Sand



60mm M49A3
Silt-Sand
Silt: Thickness 0.1 m, SNUM 5.5
Impact Velocity (m/s)
Impact Angle (deg)
0.05 m
0.075 m
0.1 m
0.125 m
SNUM Sand
6
7
8.5
Penetration CG
0.050 m
0.075 m
0.100 m
0.125 m
0.150 m
0.175 m
0.200 m
0.225 m
0.250 m
SNUM Max Penetration CG
6 0.14 m
7 0.16 m
8.5 0.19 m
Min. impact velocity 49 m/s
Max. impact velocity 127 m/s
Min. impact angle 46 deg
Max. impact angle 82 deg

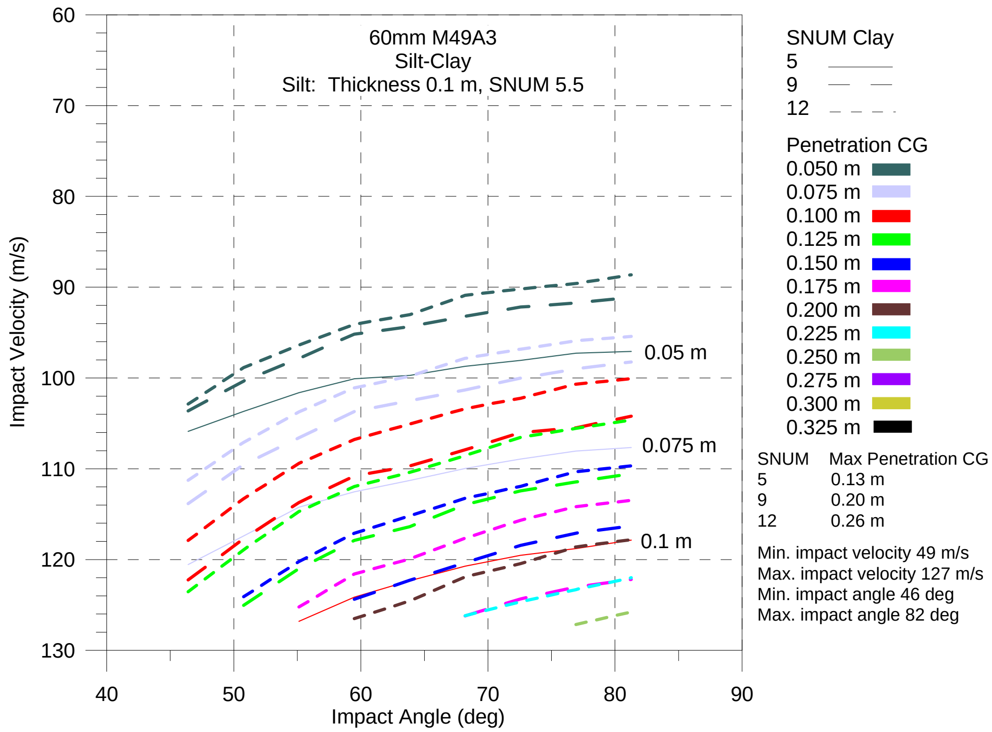


60mm M49A3
Silt-Sand
Silt: Thickness 0.1 m, SNUM 8
Impact Velocity (m/s)
Impact Angle (deg)
0.05 m
0.075 m
0.1 m
0.125 m
0.15 m
SNUM Sand
6
7
8.5
Penetration CG
0.050 m
0.075 m
0.100 m
0.125 m
0.150 m
0.175 m
0.200 m
0.225 m
SNUM Max Penetration CG
6 0.18 m
7 0.20 m
8.5 0.24 m
Min. impact velocity 49 m/s
Max. impact velocity 127 m/s
Min. impact angle 46 deg
Max. impact angle 82 deg

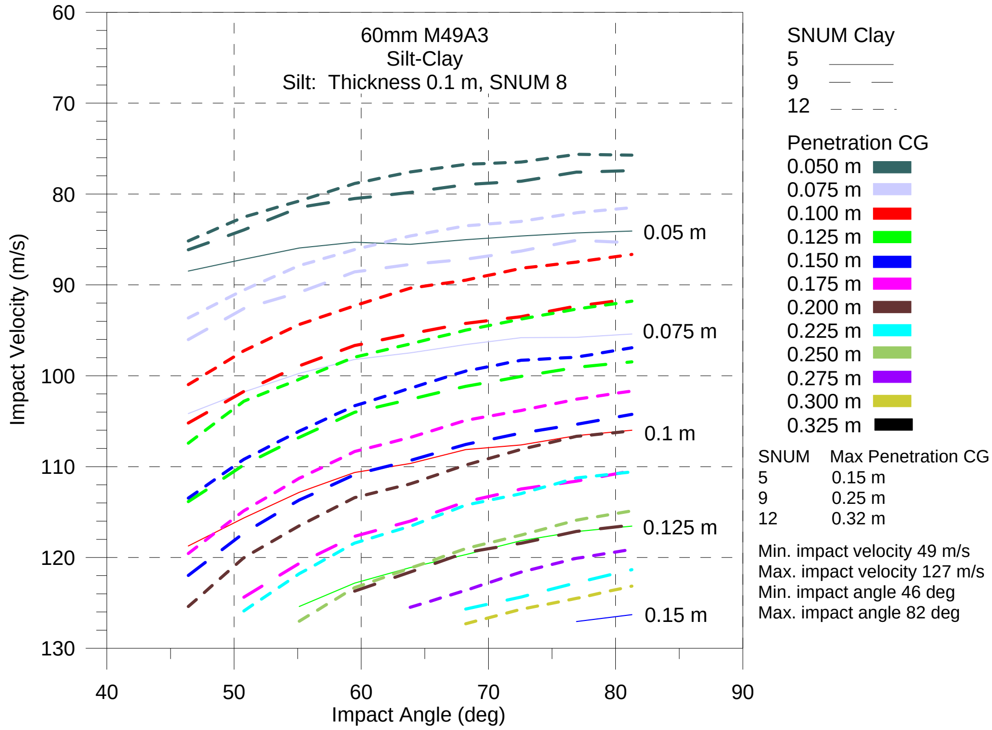


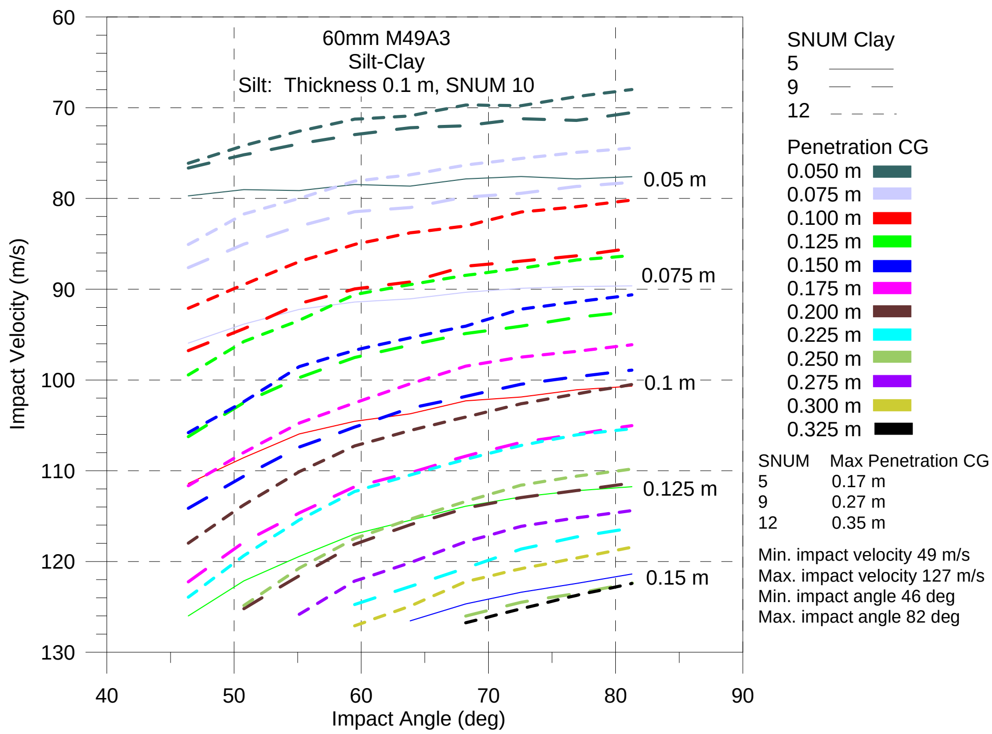
60mm M49A3
Silt-Sand
Silt: Thickness 0.1 m, SNUM 10
Impact Velocity (m/s)
Impact Angle (deg)
0.05 m
0.075 m
0.1 m
0.125 m
0.15 m
0.175 m
SNUM Sand
6
7
8.5
Penetration CG
0.050 m
0.075 m
0.100 m
0.125 m
0.150 m
0.175 m
0.200 m
0.225 m
0.250 m
SNUM Max Penetration CG
6 0.19 m
7 0.22 m
8.5 0.26 m
Min. impact velocity 49 m/s
Max. impact velocity 127 m/s
Min. impact angle 46 deg
Max. impact angle 82 deg

Silt-Clay

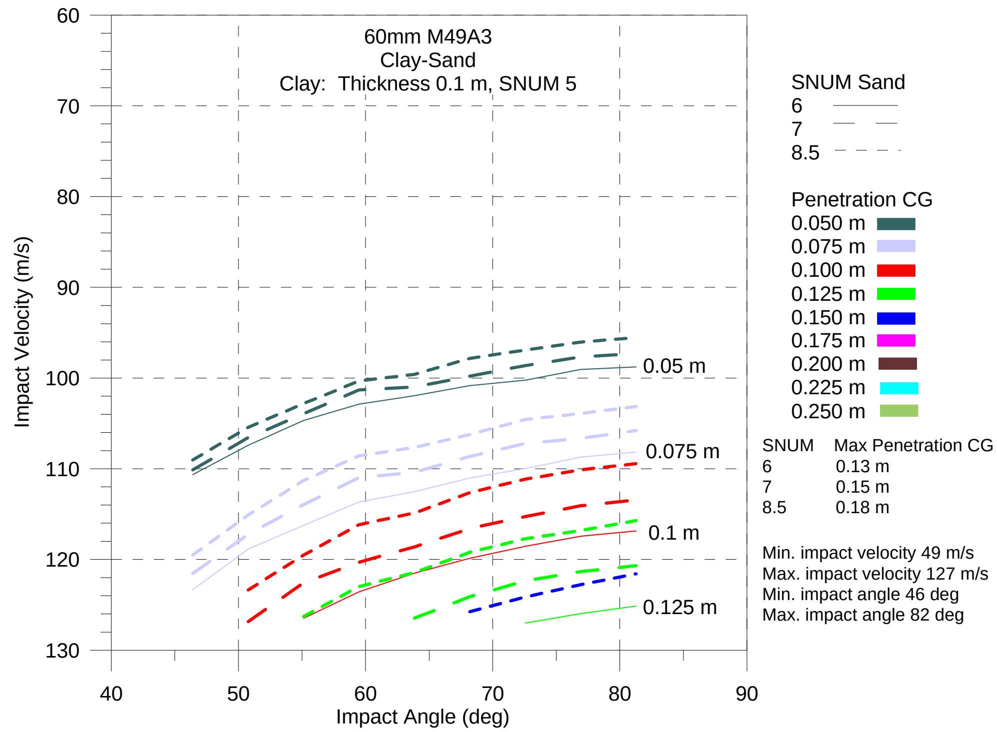


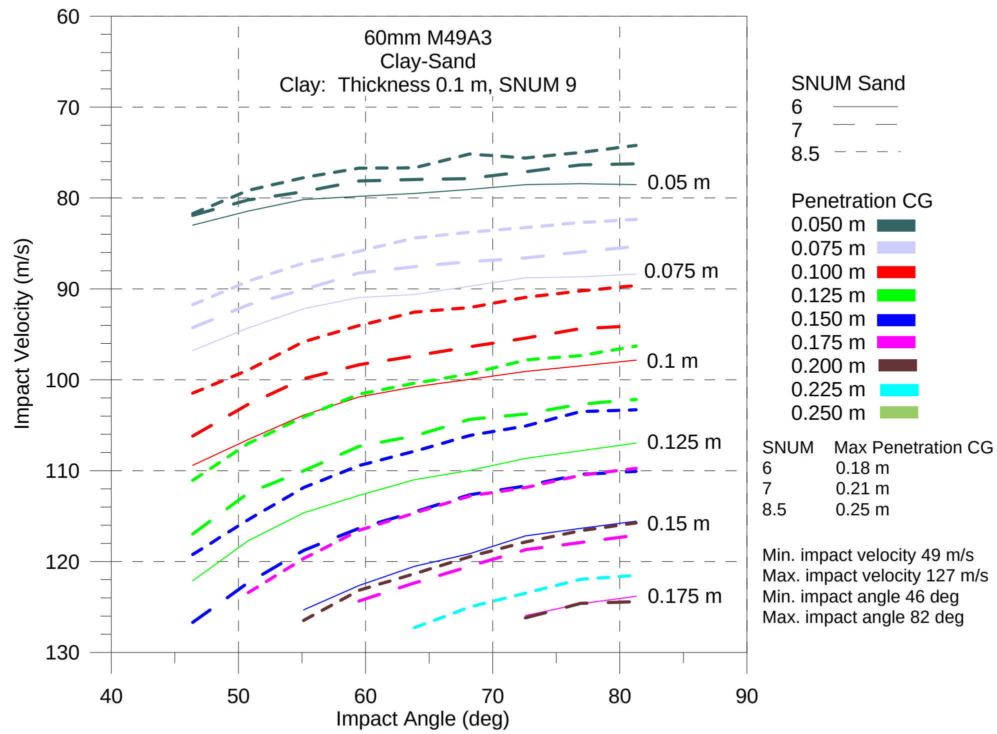
60mm M49A3
Silt-Clay
Silt: Thickness 0.1 m, SNUM 5.5
Impact Velocity (m/s)
Impact Angle (deg)
0.05 m
0.075 m
0.1 m
SNUM Clay
5
9
12
Penetration CG
0.050 m
0.075 m
0.100 m
0.125 m
0.150 m
0.175 m
0.200 m
0.225 m
0.250 m
0.275 m
0.300 m
0.325 m
SNUM Max Penetration CG
5 0.13 m
9 0.20 m
12 0.26 m
Min. impact velocity 49 m/s
Max. impact velocity 127 m/s
Min. impact angle 46 deg
Max. impact angle 82 deg

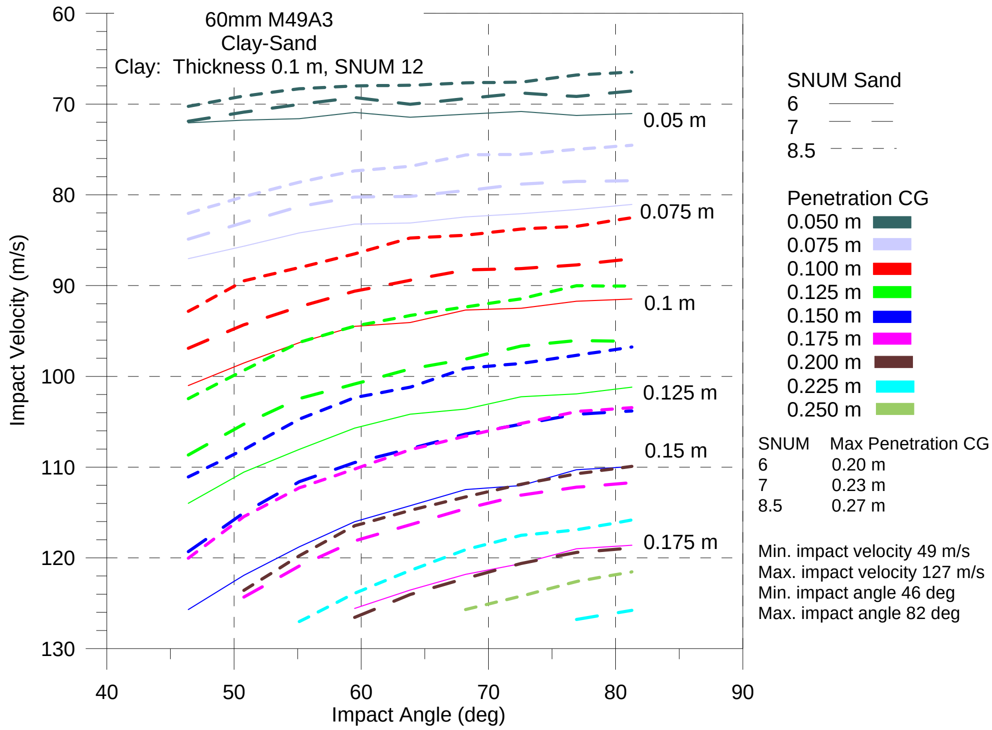

60mm M49A3
Silt-Clay
Silt: Thickness 0.1 m, SNUM 8
Impact Velocity (m/s)
Impact Angle (deg)
0.05 m
0.075 m
0.1 m
0.125 m
0.15 m
SNUM Clay
5
9
12
Penetration CG
0.050 m
0.075 m
0.100 m
0.125 m
0.150 m
0.175 m
0.200 m
0.225 m
0.250 m
0.275 m
0.300 m
0.325 m
SNUM Max Penetration CG
5 0.15 m
9 0.25 m
12 0.32 m
Min. impact velocity 49 m/s
Max. impact velocity 127 m/s
Min. impact angle 46 deg
Max. impact angle 82 deg


60mm M49A3
Silt-Clay
Silt: Thickness 0.1 m, SNUM 10
Impact Velocity (m/s)
Impact Angle (deg)
0.05 m
0.075 m
0.1 m
0.125 m
0.15 m
SNUM Clay
5
9
12
Penetration CG
0.050 m
0.075 m
0.100 m
0.125 m
0.150 m
0.175 m
0.200 m
0.225 m
0.250 m
0.275 m
0.300 m
0.325 m
SNUM Max Penetration CG
5 0.17 m
9 0.27 m
12 0.35 m
Min. impact velocity 49 m/s
Max. impact velocity 127 m/s
Min. impact angle 46 deg
Max. impact angle 82 deg

Clay-Sand

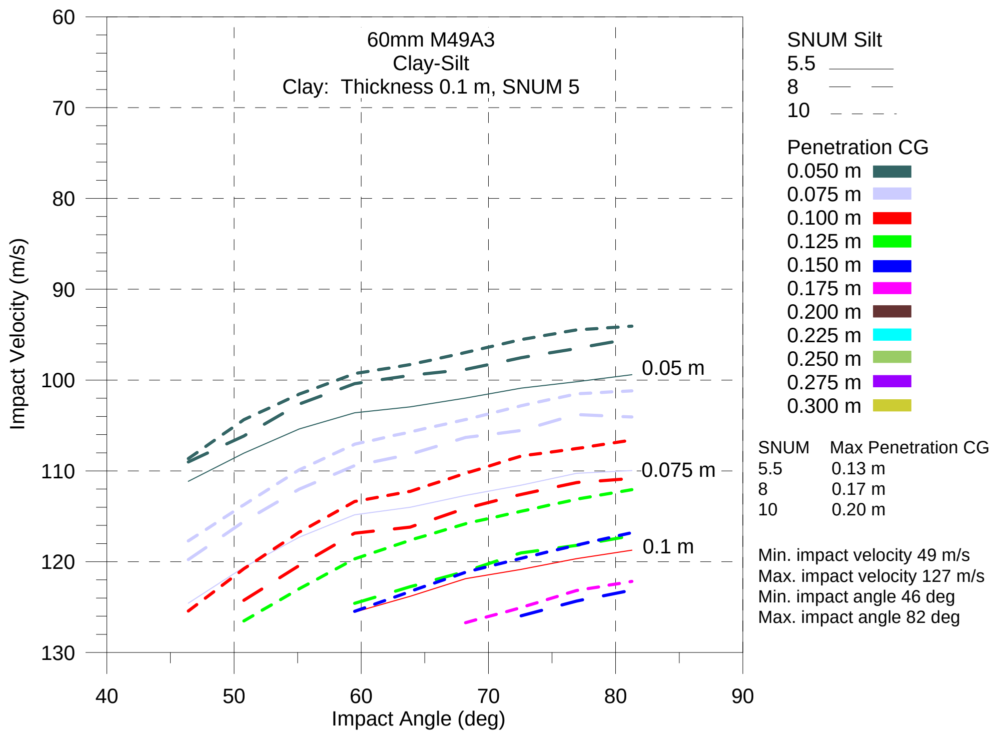

60mm M49A3
Clay-Sand
Clay: Thickness 0.1 m, SNUM 5
Impact Velocity (m/s)
Impact Angle (deg)
0.05 m
0.075 m
0.1 m
0.125 m
SNUM Sand
6
7
8.5
Penetration CG
0.050 m
0.075 m
0.100 m
0.125 m
0.150 m
0.175 m
0.200 m
0.225 m
0.250 m
SNUM Max Penetration CG
6 0.13 m
7 0.15 m
8.5 0.18 m
Min. impact velocity 49 m/s
Max. impact velocity 127 m/s
Min. impact angle 46 deg
Max. impact angle 82 deg


60mm M49A3
Clay-Sand
Clay: Thickness 0.1 m, SNUM 9
Impact Velocity (m/s)
Impact Angle (deg)
0.05 m
0.075 m
0.1 m
0.125 m
0.15 m
0.175 m
SNUM Sand
6
7
8.5
Penetration CG
0.050 m
0.075 m
0.100 m
0.125 m
0.150 m
0.175 m
0.200 m
0.225 m
0.250 m
SNUM Max Penetration CG
6 0.18 m
7 0.21 m
8.5 0.25 m
Min. impact velocity 49 m/s
Max. impact velocity 127 m/s
Min. impact angle 46 deg
Max. impact angle 82 deg

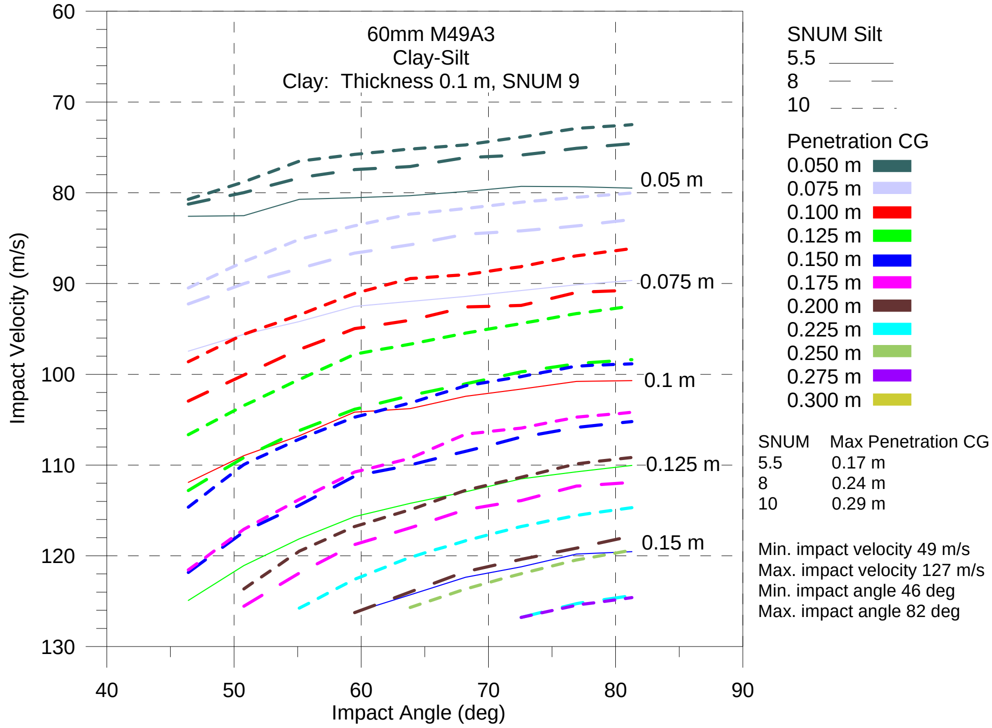


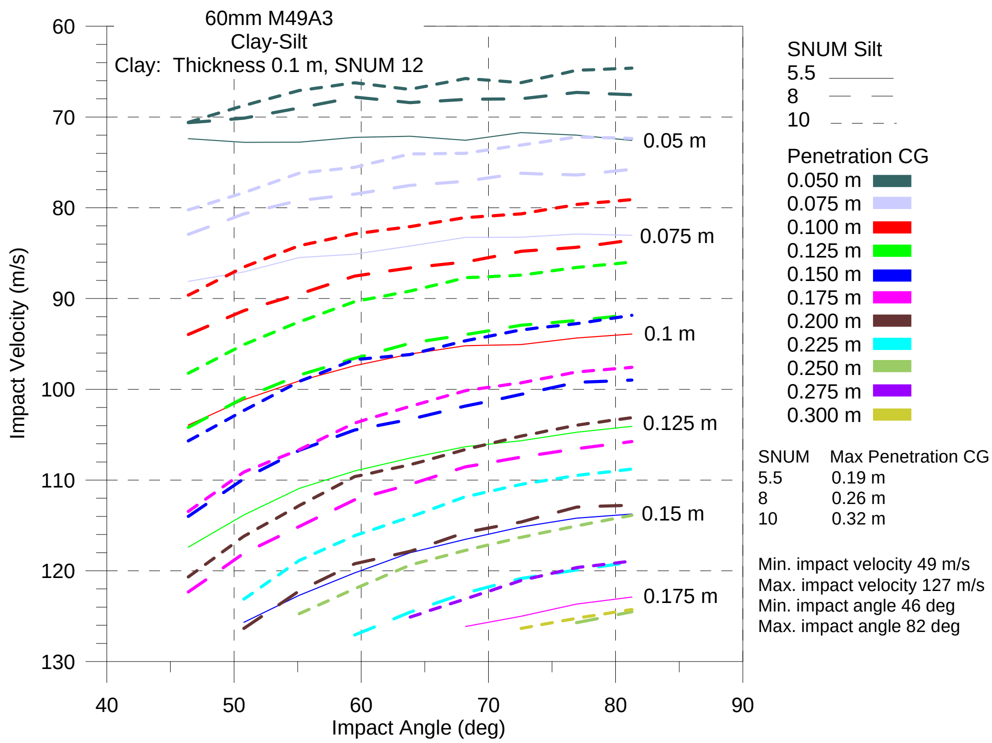
60mm M49A3
Clay-Sand
Clay: Thickness 0.1 m, SNUM 12
Impact Velocity (m/s)
Impact Angle (deg)
0.05 m
0.075 m
0.1 m
0.125 m
0.15 m
0.175 m
SNUM Sand
6
7
8.5
Penetration CG
0.050 m
0.075 m
0.100 m
0.125 m
0.150 m
0.175 m
0.200 m
0.225 m
0.250 m
SNUM Max Penetration CG
6 0.20 m
7 0.23 m
8.5 0.27 m
Min. impact velocity 49 m/s
Max. impact velocity 127 m/s
Min. impact angle 46 deg
Max. impact angle 82 deg

Clay-Silt



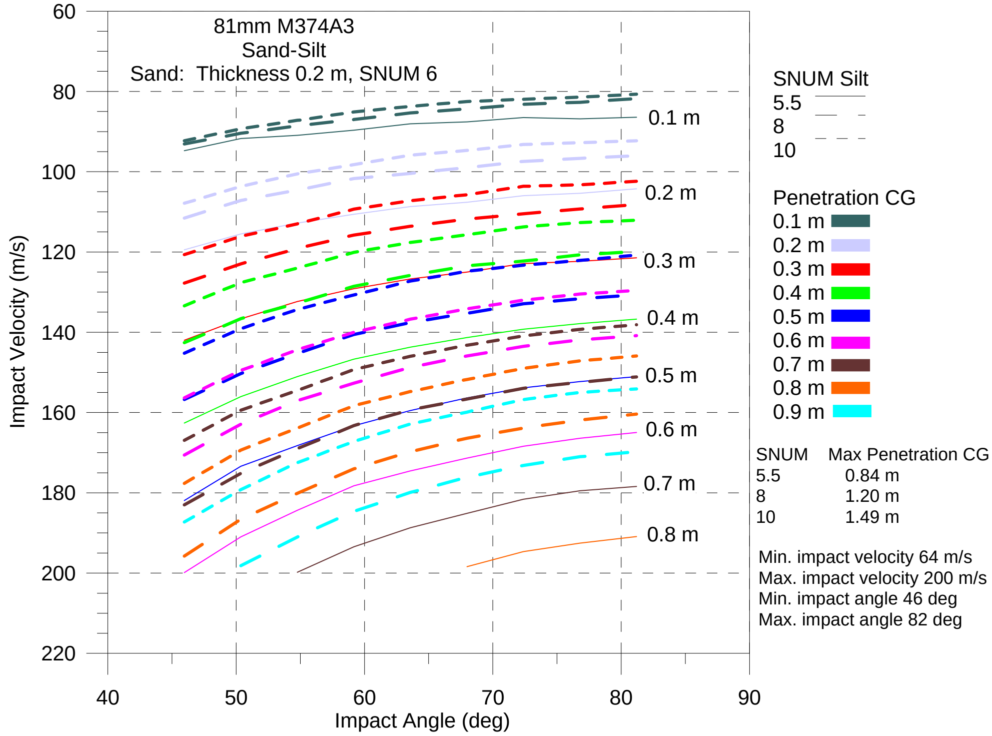
60mm M49A3
Clay-Silt
Clay: Thickness 0.1 m, SNUM 5
Impact Velocity (m/s)
Impact Angle (deg)
0.05 m
0.075 m
0.1 m
SNUM Silt
5.5
8
10
Penetration CG
0.050 m
0.075 m
0.100 m
0.125 m
0.150 m
0.175 m
0.200 m
0.225 m
0.250 m
0.275 m
0.300 m
SNUM Max Penetration CG
5.5 0.13 m
8 0.17 m
10 0.20 m
Min. impact velocity 49 m/s
Max. impact velocity 127 m/s
Min. impact angle 46 deg
Max. impact angle 82 deg

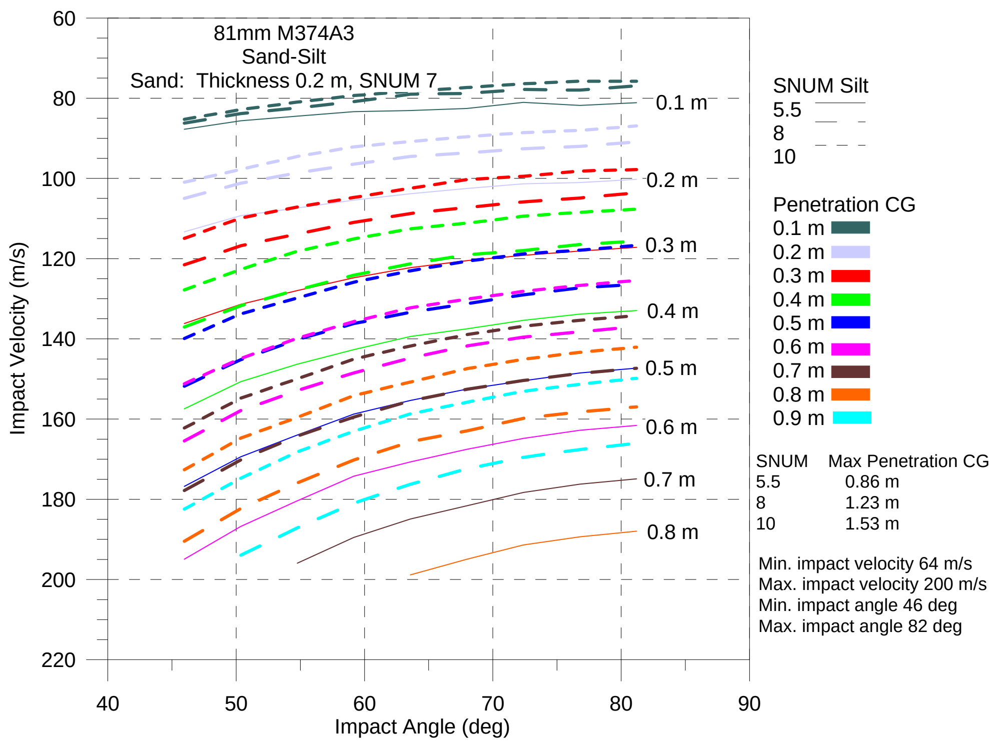

60mm M49A3
Clay-Silt
Clay: Thickness 0.1 m, SNUM 9
Impact Velocity (m/s)
Impact Angle (deg)
0.05 m
0.075 m
0.1 m
0.125 m
0.15 m
SNUM Silt
5.5
8
10
Penetration CG
0.050 m
0.075 m
0.100 m
0.125 m
0.150 m
0.175 m
0.200 m
0.225 m
0.250 m
0.275 m
0.300 m
SNUM Max Penetration CG
5.5 0.17 m
8 0.24 m
10 0.29 m
Min. impact velocity 49 m/s
Max. impact velocity 127 m/s
Min. impact angle 46 deg
Max. impact angle 82 deg

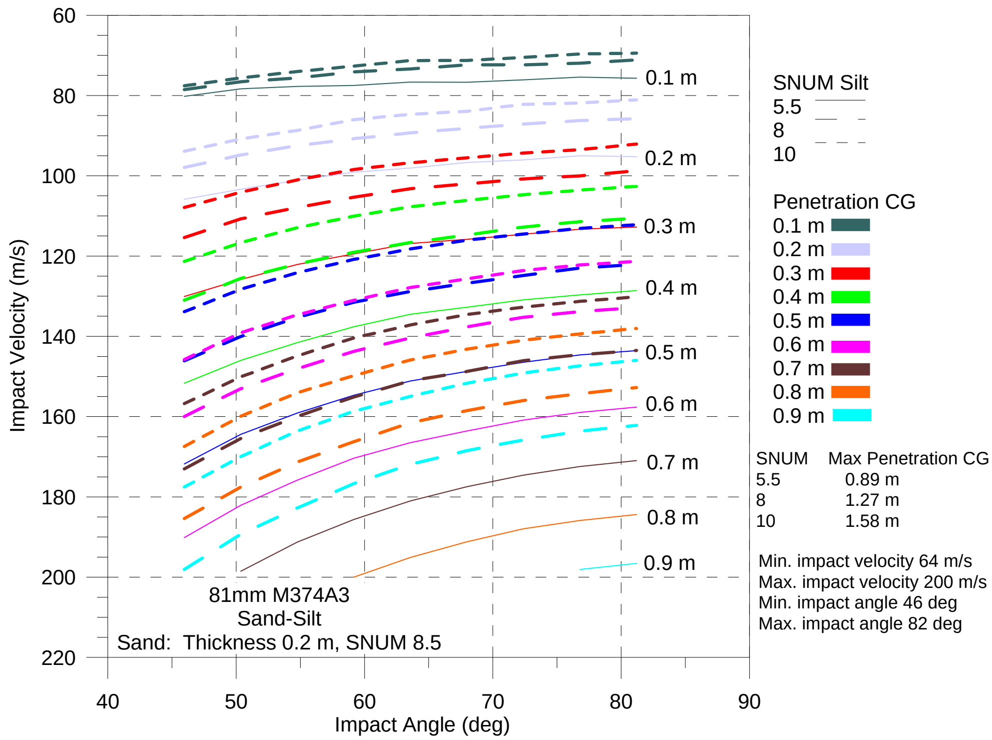

60mm M49A3
Clay-Silt
Clay: Thickness 0.1 m, SNUM 12
Impact Velocity (m/s)
Impact Angle (deg)
0.05 m
0.075 m
0.1 m
0.125 m
0.15 m
0.175 m
SNUM Silt
5.5
8
10
Penetration CG
0.050 m
0.075 m
0.100 m
0.125 m
0.150 m
0.175 m
0.200 m
0.225 m
0.250 m
0.275 m
0.300 m
SNUM Max Penetration CG
5.5 0.19 m
8 0.26 m
10 0.32 m
Min. impact velocity 49 m/s
Max. impact velocity 127 m/s
Min. impact angle 46 deg
Max. impact angle 82 deg

81mm 374A3

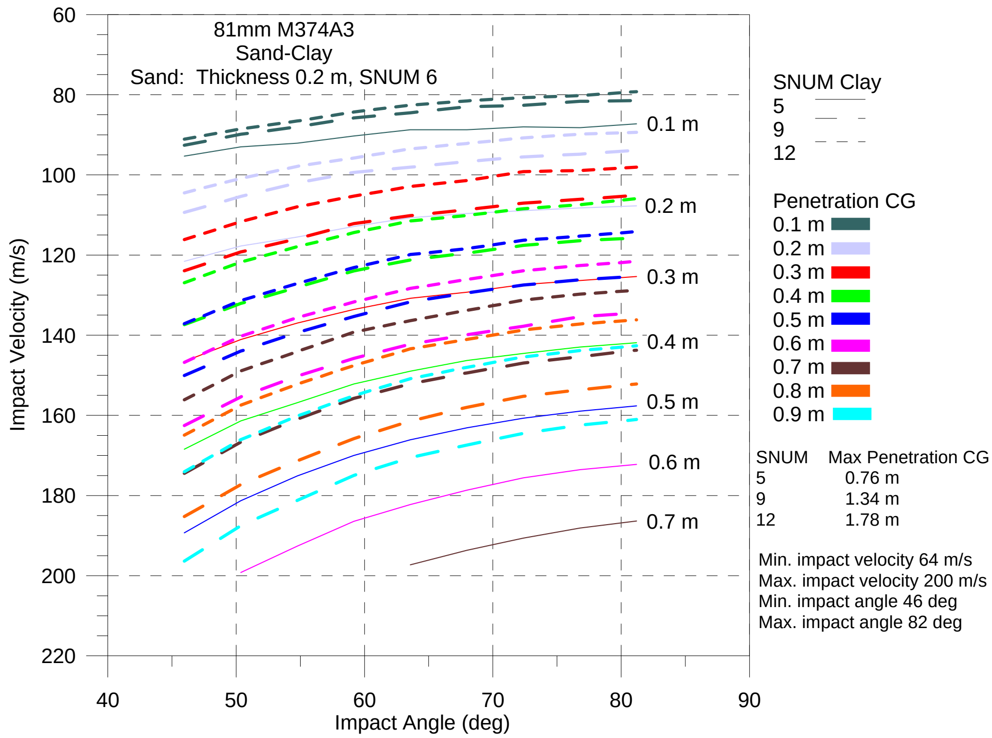
Sand-Silt

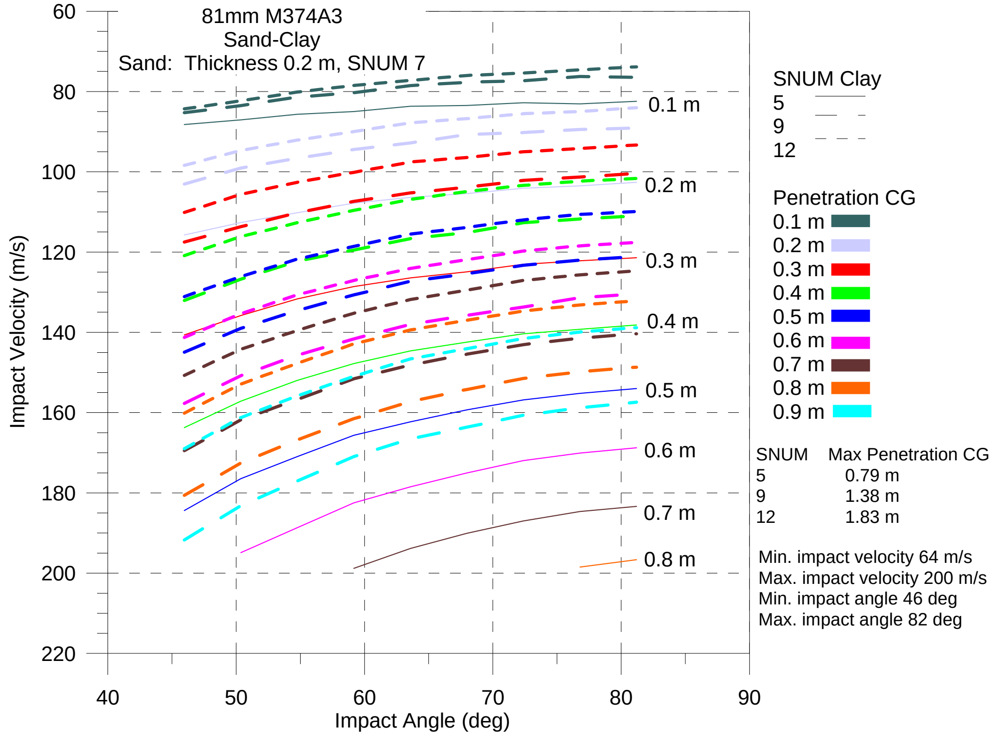




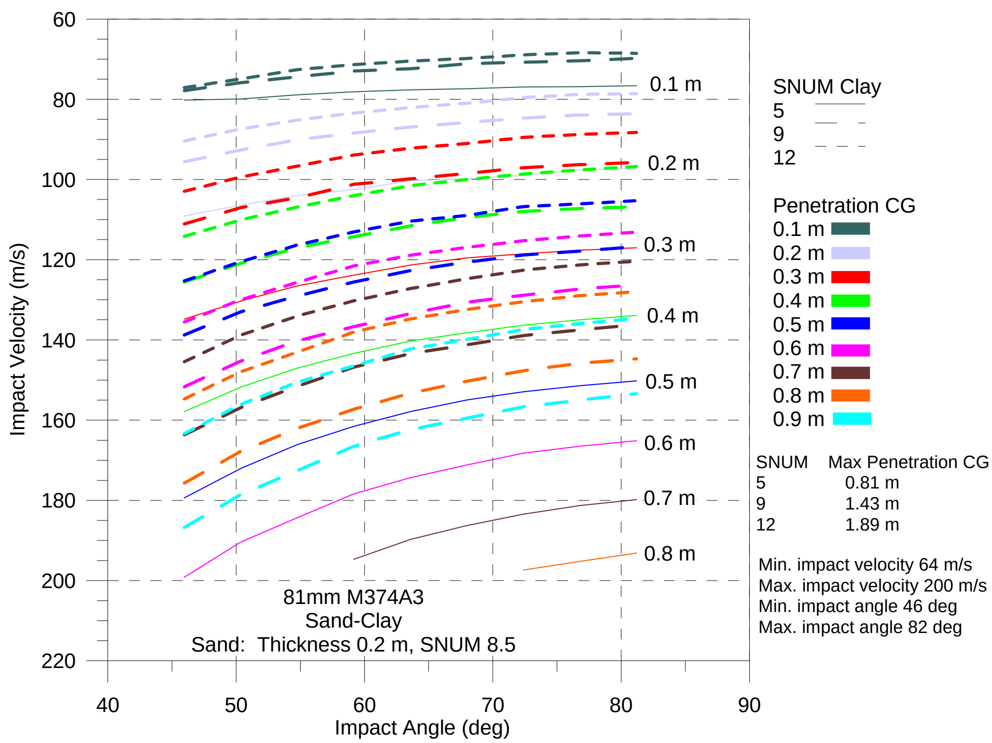

81mm M374A3
Sand-Silt
Sand: Thickness 0.2 m, SNUM 8.5
Impact Velocity (m/s)
Impact Angle (deg)
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
SNUM Silt
5.5
8
10
Penetration CG
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
SNUM Max Penetration CG
5.5 0.89 m
8 1.27 m
10 1.58 m
Min. impact velocity 64 m/s
Max. impact velocity 200 m/s
Min. impact angle 46 deg
Max. impact angle 82 deg

Sand-Clay


81mm M374A3
Sand-Clay
Sand: Thickness 0.2 m, SNUM 6
Impact Velocity (m/s)
Impact Angle (deg)
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
SNUM Clay
5
9
12
Penetration CG
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
SNUM Max Penetration CG
5 0.76 m
9 1.34 m
12 1.78 m
Min. impact velocity 64 m/s
Max. impact velocity 200 m/s
Min. impact angle 46 deg
Max. impact angle 82 deg

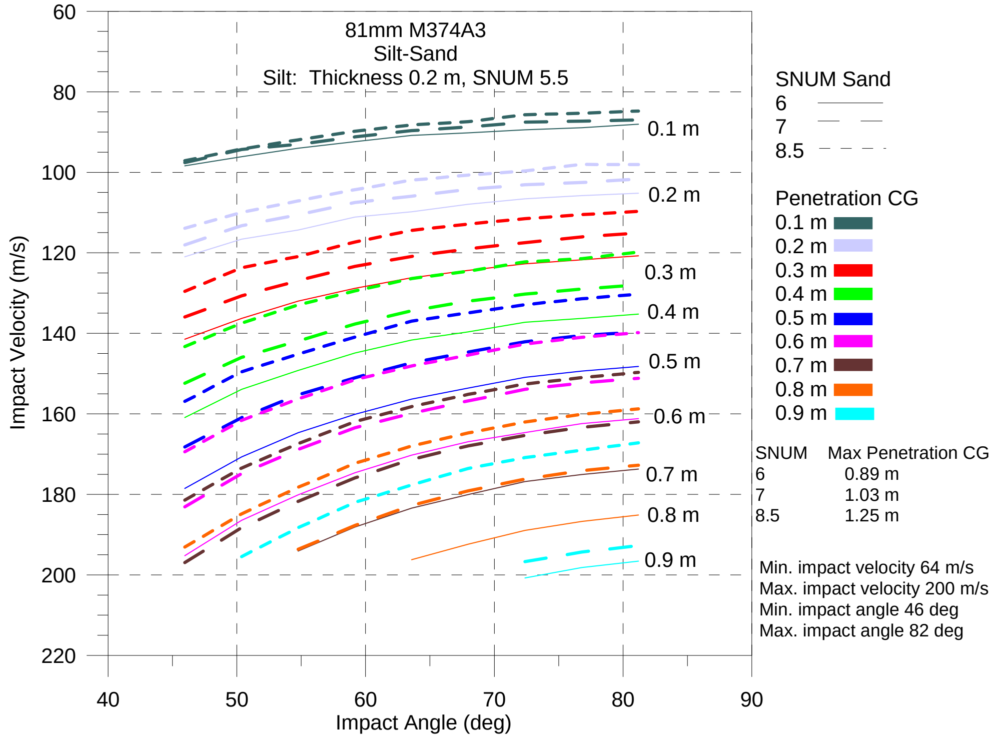


81mm M374A3
Sand-Clay
Sand: Thickness 0.2 m, SNUM 7
Impact Velocity (m/s)
Impact Angle (deg)
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
SNUM Clay
5
9
12
Penetration CG
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
SNUM Max Penetration CG
5 0.79 m
9 1.38 m
12 1.83 m
Min. impact velocity 64 m/s
Max. impact velocity 200 m/s
Min. impact angle 46 deg
Max. impact angle 82 deg

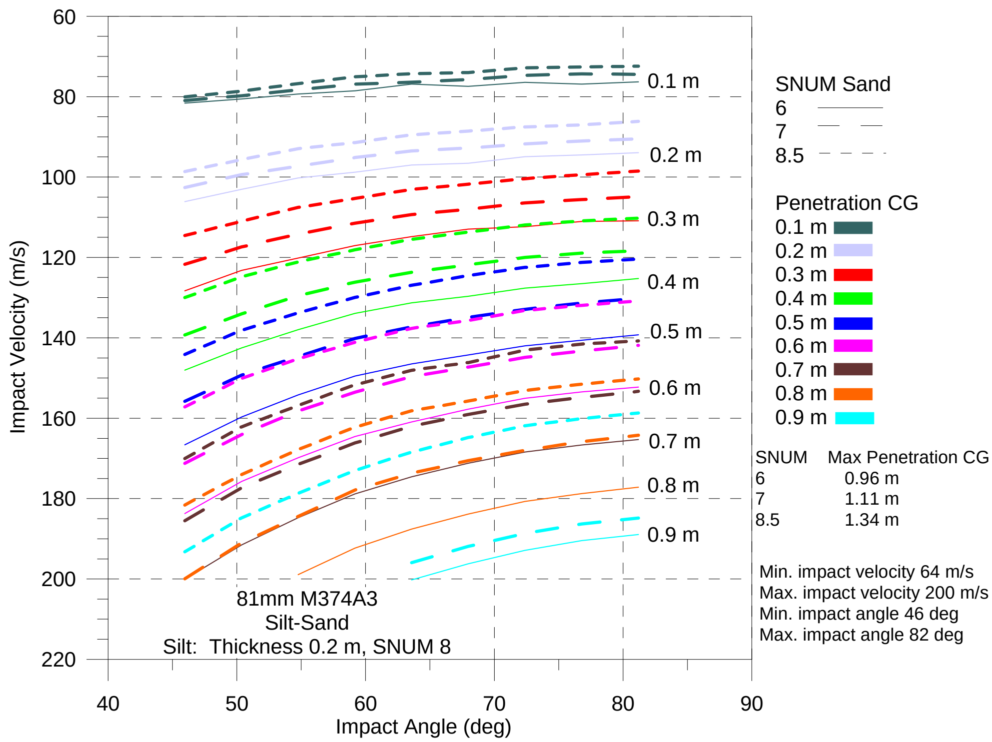


81mm M374A3
Sand-Clay
Sand: Thickness 0.2 m, SNUM 8.5
Impact Velocity (m/s)
Impact Angle (deg)
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
SNUM Clay
5
9
12
Penetration CG
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
SNUM Max Penetration CG
5 0.81 m
9 1.43 m
12 1.89 m
Min. impact velocity 64 m/s
Max. impact velocity 200 m/s
Min. impact angle 46 deg
Max. impact angle 82 deg

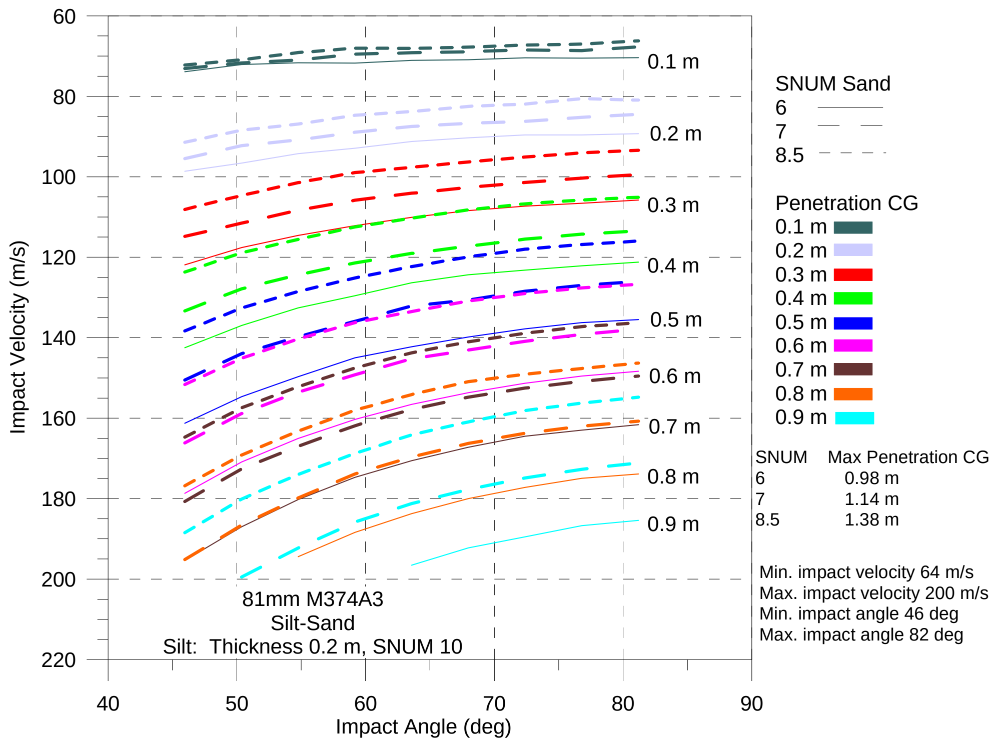
Silt-Sand



81mm M374A3
Silt-Sand
Silt: Thickness 0.2 m, SNUM 5.5
Impact Velocity (m/s)
Impact Angle (deg)
60
80
100
120
140
160
180
200
220
40
50
60
70
80
90
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
SNUM Sand
6
7
8.5
Penetration CG
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
SNUM Max Penetration CG
6 0.89 m
7 1.03 m
8.5 1.25 m
Min. impact velocity 64 m/s
Max. impact velocity 200 m/s
Min. impact angle 46 deg
Max. impact angle 82 deg

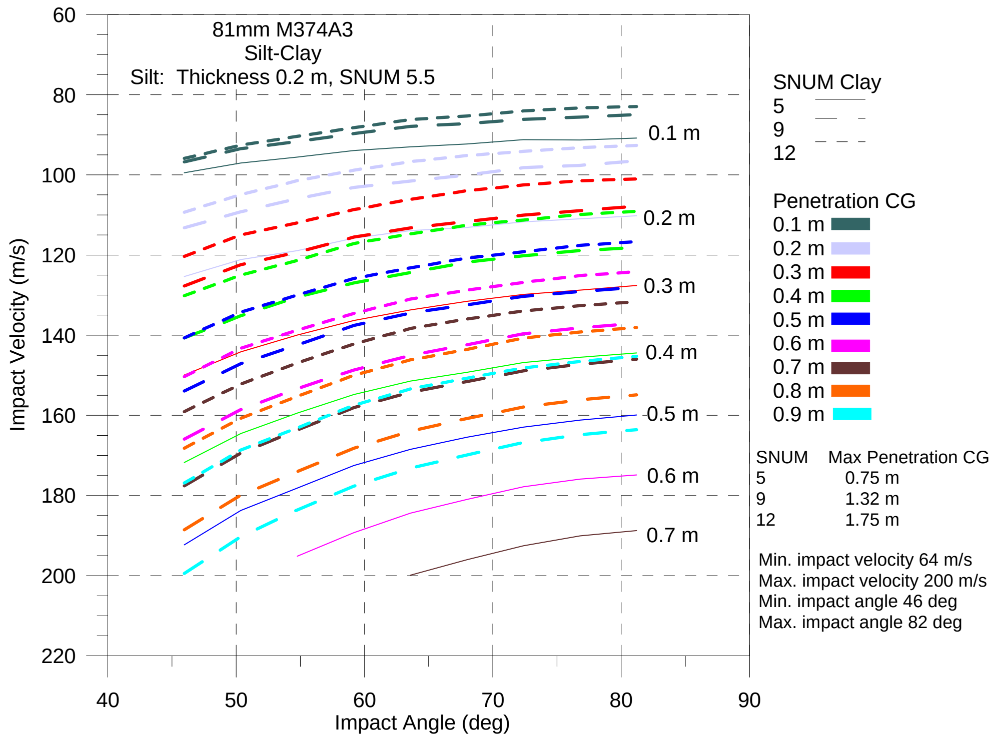


81mm M374A3
Silt-Sand
Silt: Thickness 0.2 m, SNUM 8
Impact Velocity (m/s)
Impact Angle (deg)
60
80
100
120
140
160
180
200
220
40
50
60
70
80
90
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
SNUM Sand
6
7
8.5
Penetration CG
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
SNUM Max Penetration CG
6 0.96 m
7 1.11 m
8.5 1.34 m
Min. impact velocity 64 m/s
Max. impact velocity 200 m/s
Min. impact angle 46 deg
Max. impact angle 82 deg

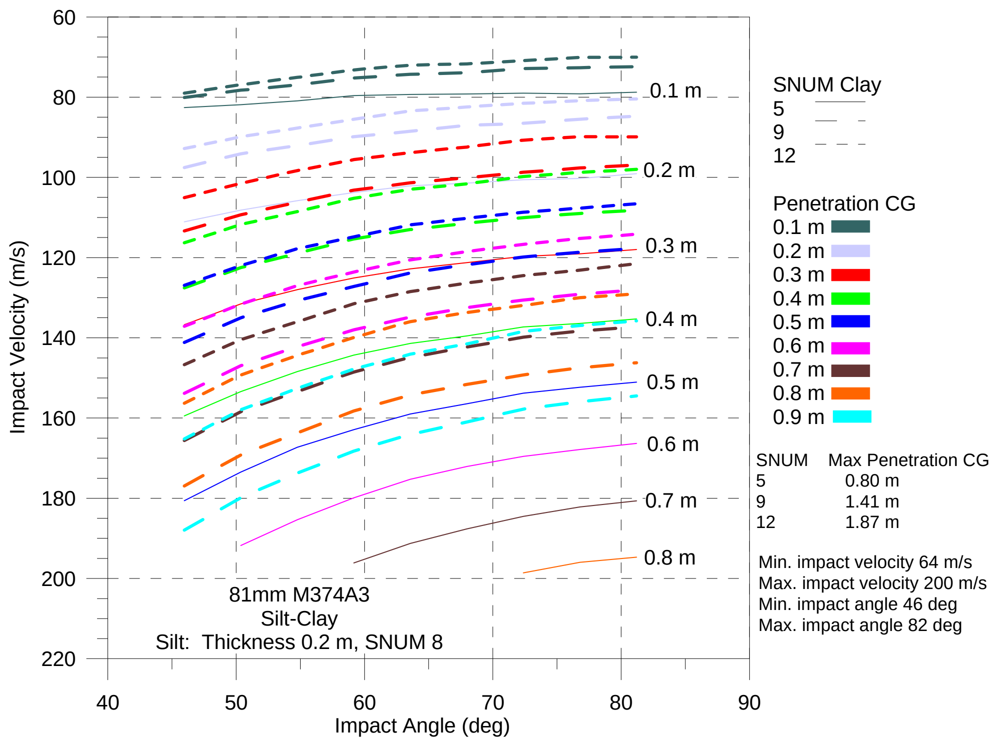


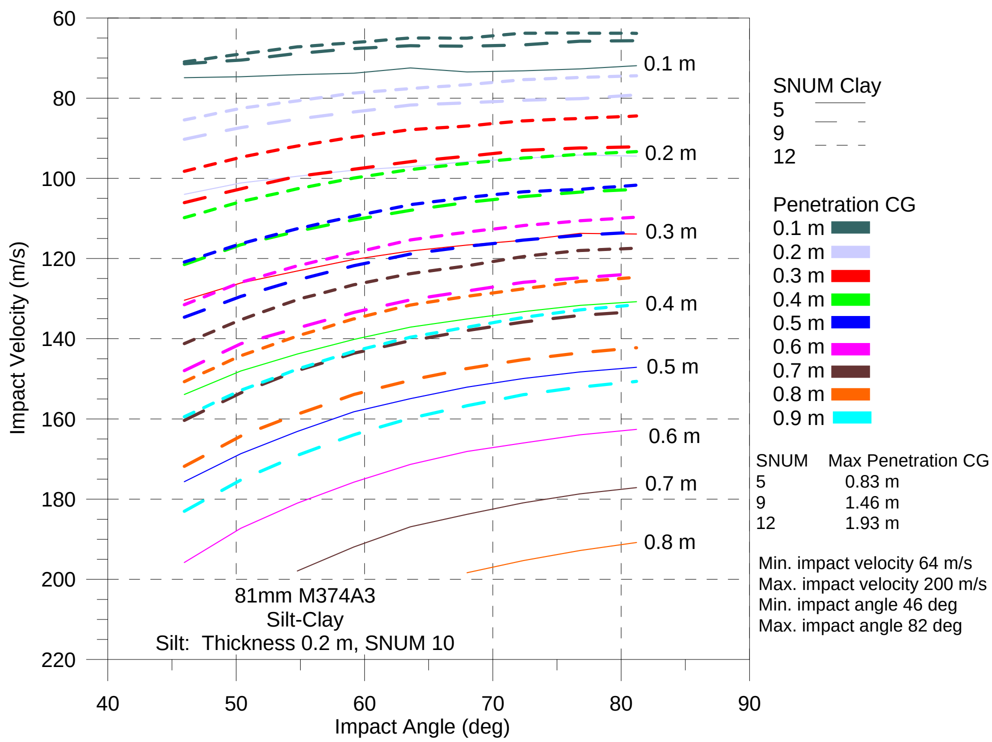
81mm M374A3
Silt-Sand
Silt: Thickness 0.2 m, SNUM 10
Impact Velocity (m/s)
Impact Angle (deg)
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
SNUM Sand
6
7
8.5
Penetration CG
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
SNUM Max Penetration CG
6 0.98 m
7 1.14 m
8.5 1.38 m
Min. impact velocity 64 m/s
Max. impact velocity 200 m/s
Min. impact angle 46 deg
Max. impact angle 82 deg

Silt-Clay

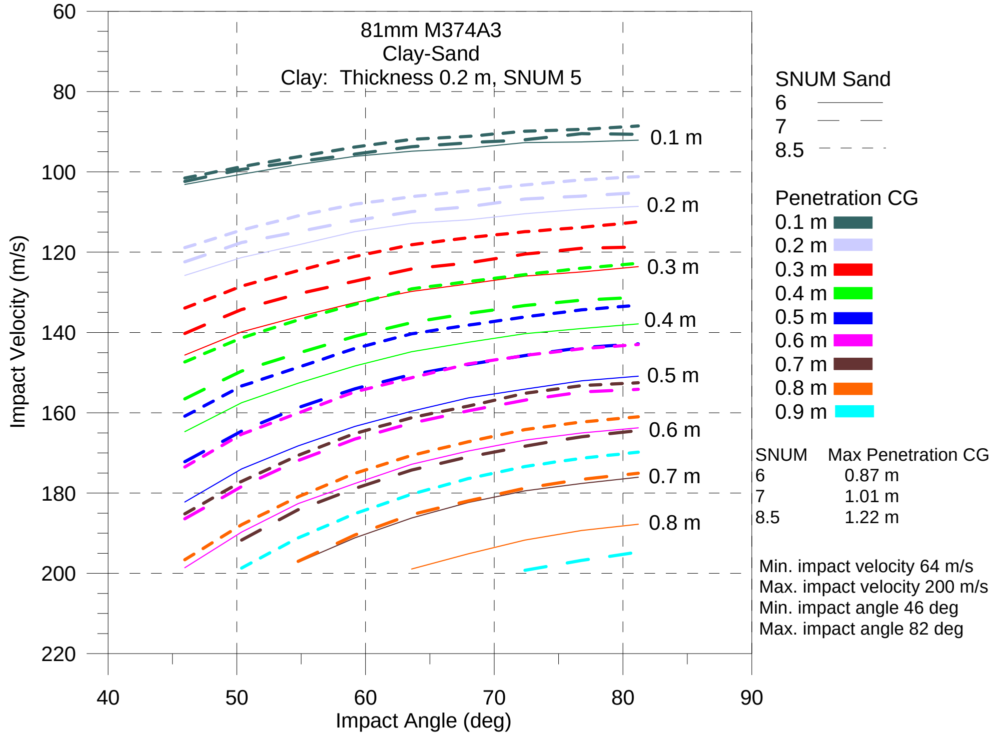


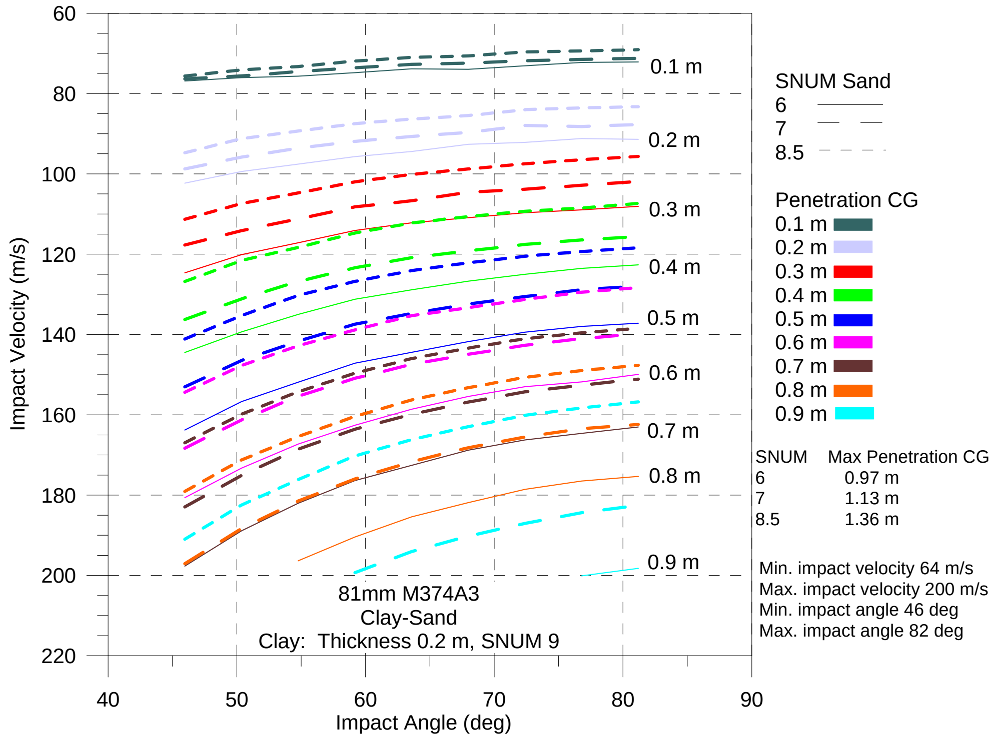
81mm M374A3
Silt-Clay
Silt: Thickness 0.2 m, SNUM 5.5
Impact Velocity (m/s)
Impact Angle (deg)
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
SNUM Clay
5
9
12
Penetration CG
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
SNUM Max Penetration CG
5 0.75 m
9 1.32 m
12 1.75 m
Min. impact velocity 64 m/s
Max. impact velocity 200 m/s
Min. impact angle 46 deg
Max. impact angle 82 deg

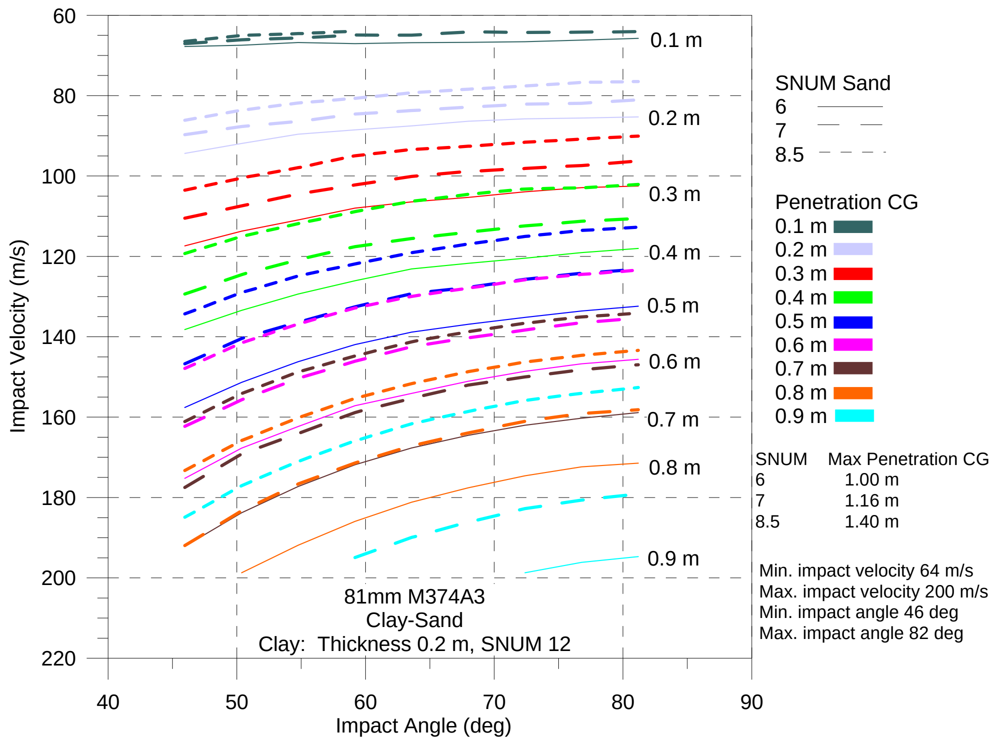

Impact Velocity (m/s)
Impact Angle (deg)
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
81mm M374A3
Silt-Clay
Silt: Thickness 0.2 m, SNUM 8
SNUM Clay
5
9
12
Penetration CG
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
SNUM Max Penetration CG
5 0.80 m
9 1.41 m
12 1.87 m
Min. impact velocity 64 m/s
Max. impact velocity 200 m/s
Min. impact angle 46 deg
Max. impact angle 82 deg


Impact Velocity (m/s)
Impact Angle (deg)
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
81mm M374A3
Silt-Clay
Silt: Thickness 0.2 m, SNUM 10
SNUM Clay
5
9
12
Penetration CG
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
SNUM Max Penetration CG
5 0.83 m
9 1.46 m
12 1.93 m
Min. impact velocity 64 m/s
Max. impact velocity 200 m/s
Min. impact angle 46 deg
Max. impact angle 82 deg

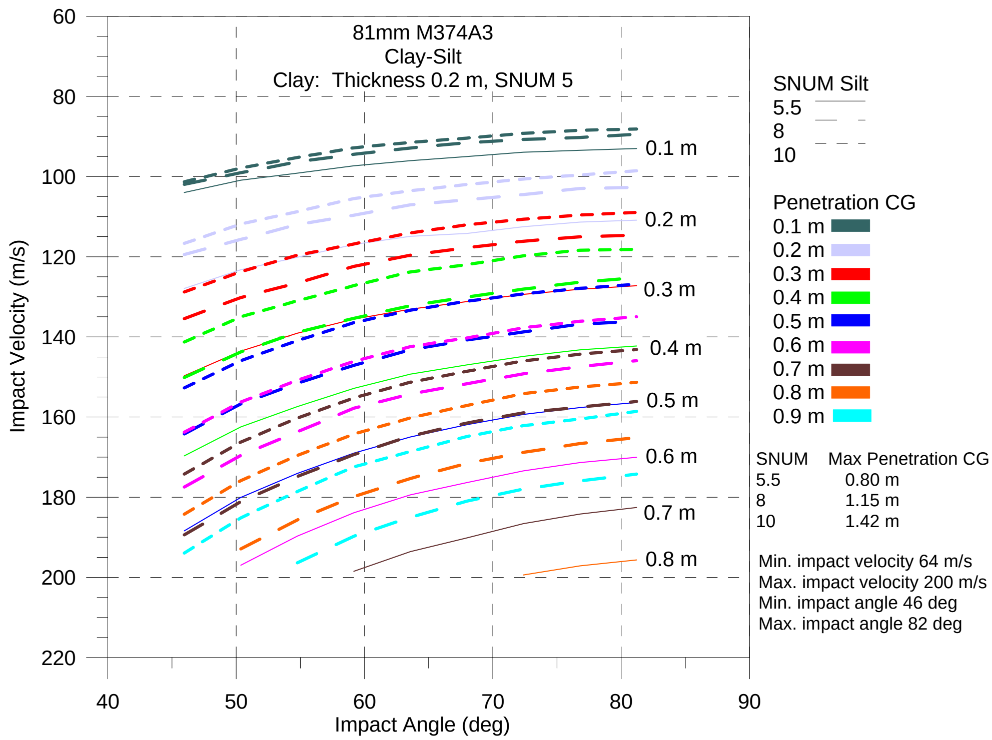
Clay-Sand

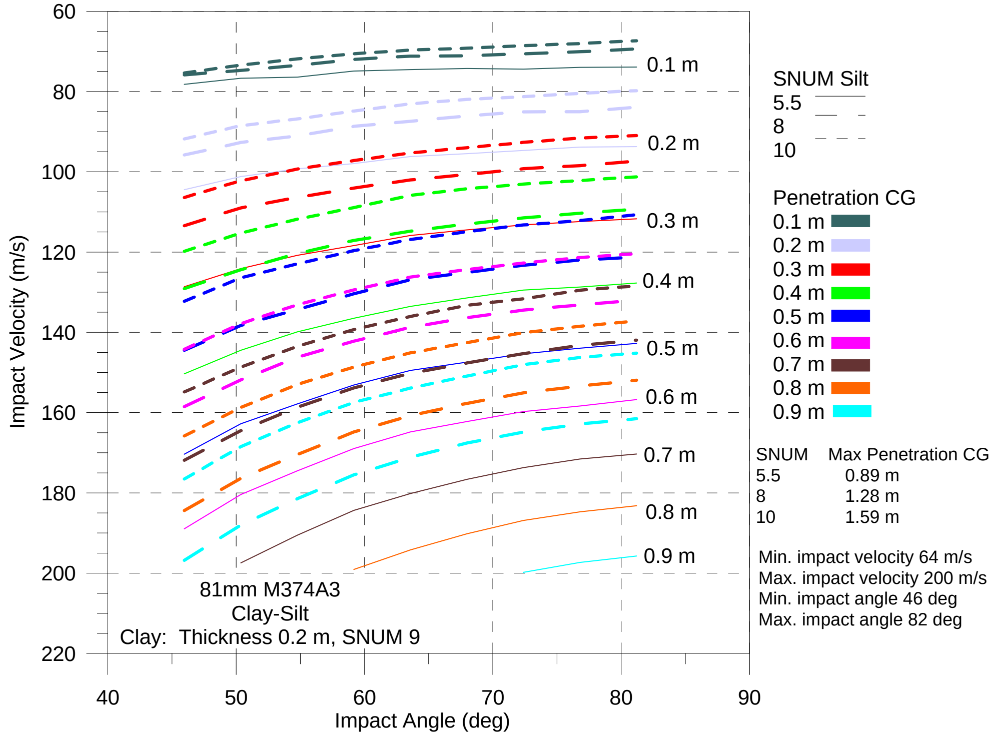

81mm M374A3
Clay-Sand
Clay: Thickness 0.2 m, SNUM 5
Impact Velocity (m/s)
Impact Angle (deg)
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
SNUM Sand
6
7
8.5
Penetration CG
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
SNUM Max Penetration CG
6 0.87 m
7 1.01 m
8.5 1.22 m
Min. impact velocity 64 m/s
Max. impact velocity 200 m/s
Min. impact angle 46 deg
Max. impact angle 82 deg


81mm M374A3
Clay-Sand
Clay: Thickness 0.2 m, SNUM 9
Impact Velocity (m/s)
Impact Angle (deg)
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
SNUM Sand
6
7
8.5
Penetration CG
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
SNUM Max Penetration CG
6 0.97 m
7 1.13 m
8.5 1.36 m
Min. impact velocity 64 m/s
Max. impact velocity 200 m/s
Min. impact angle 46 deg
Max. impact angle 82 deg

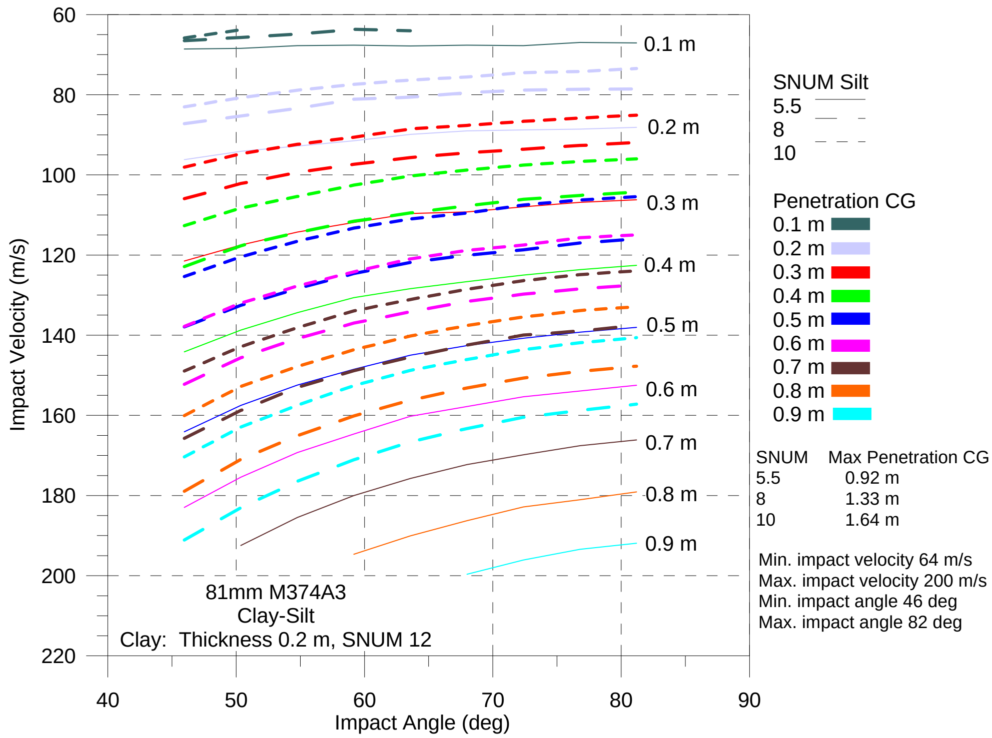

81mm M374A3
Clay-Sand
Clay: Thickness 0.2 m, SNUM 12
Impact Velocity (m/s)
Impact Angle (deg)
60
80
100
120
140
160
180
200
220
40
50
60
70
80
90
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
SNUM Sand
6
7
8.5
Penetration CG
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
SNUM Max Penetration CG
6 1.00 m
7 1.16 m
8.5 1.40 m
Min. impact velocity 64 m/s
Max. impact velocity 200 m/s
Min. impact angle 46 deg
Max. impact angle 82 deg

Clay-Silt


81mm M374A3
Clay-Silt
Clay: Thickness 0.2 m, SNUM 5
Impact Velocity (m/s)
Impact Angle (deg)
60
80
100
120
140
160
180
200
220
40
50
60
70
80
90
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
SNUM Silt
5.5
8
10
Penetration CG
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
SNUM Max Penetration CG
5.5 0.80 m
8 1.15 m
10 1.42 m
Min. impact velocity 64 m/s
Max. impact velocity 200 m/s
Min. impact angle 46 deg
Max. impact angle 82 deg



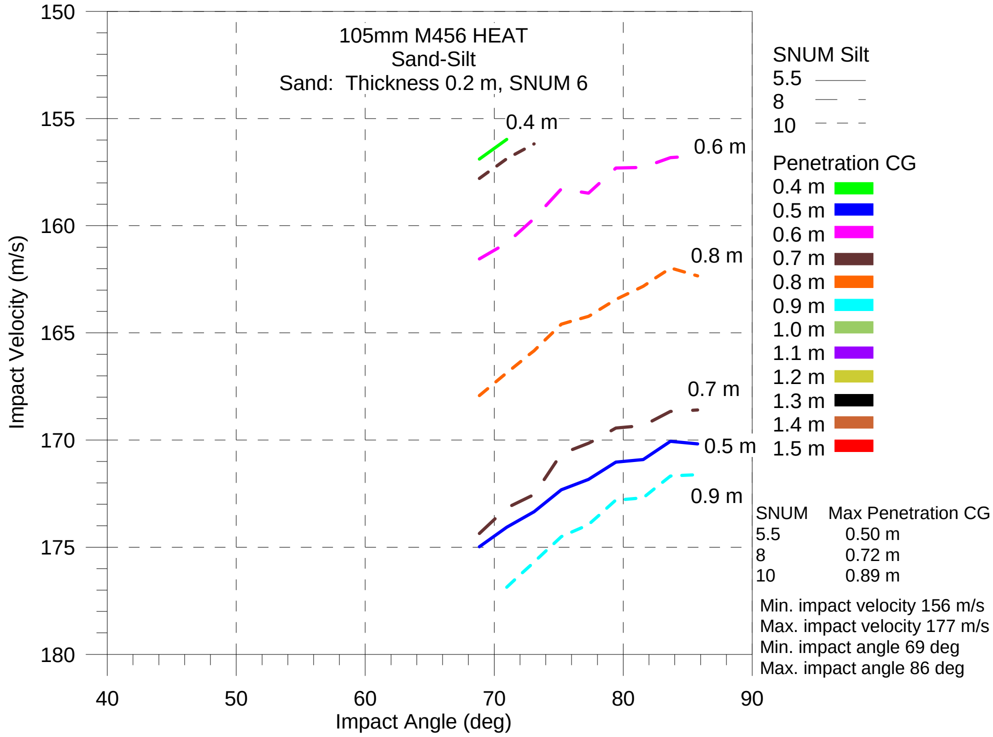
60
80
100
120
140
160
180
200
220
Impact Velocity (m/s)
40
50
60
70
80
90
Impact Angle (deg)
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
81mm M374A3
Clay-Silt
Clay: Thickness 0.2 m, SNUM 9
SNUM Silt
5.5
8
10
Penetration CG
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
SNUM Max Penetration CG
5.5 0.89 m
8 1.28 m
10 1.59 m
Min. impact velocity 64 m/s
Max. impact velocity 200 m/s
Min. impact angle 46 deg
Max. impact angle 82 deg

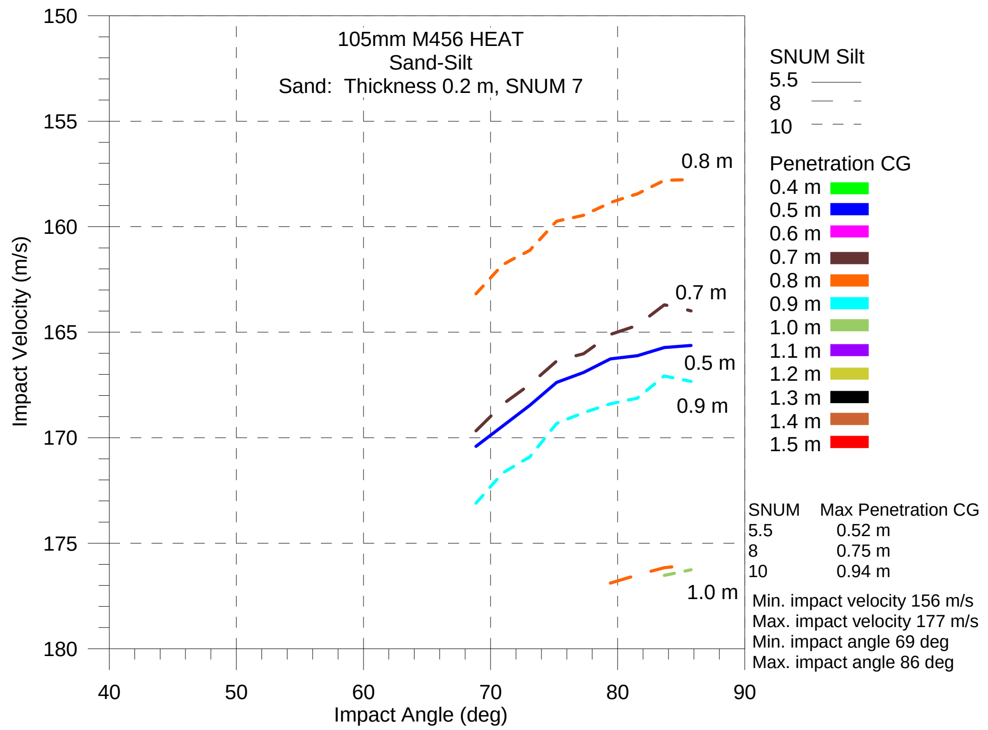


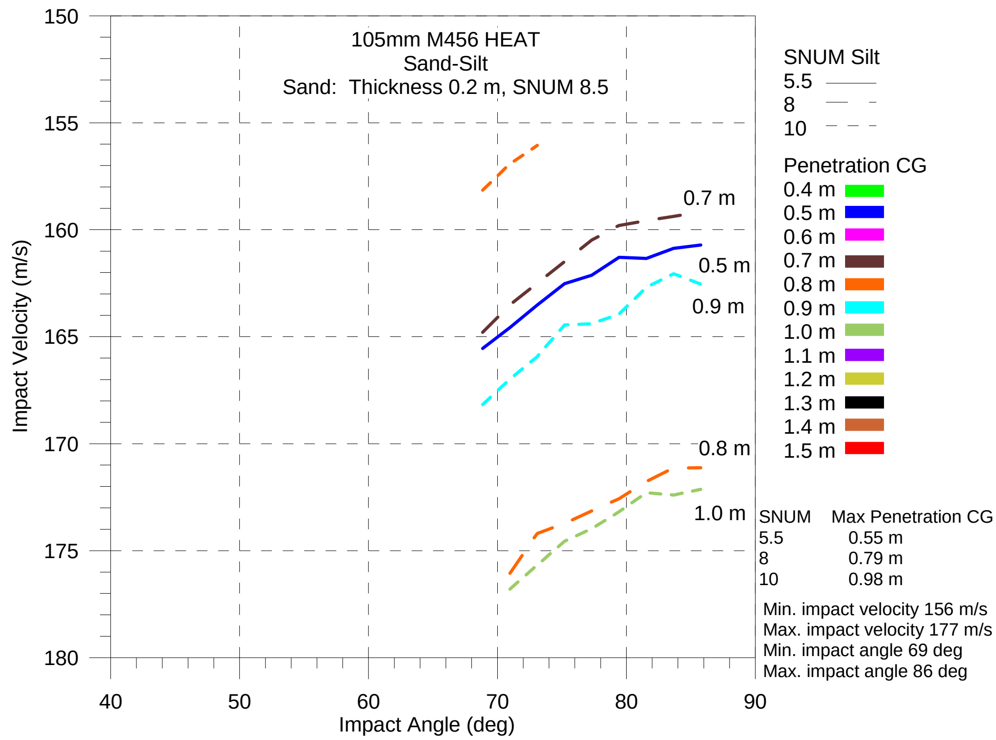
60
80
100
120
140
160
180
200
220
Impact Velocity (m/s)
40
50
60
70
80
90
Impact Angle (deg)
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
81mm M374A3
Clay-Silt
Clay: Thickness 0.2 m, SNUM 12
SNUM Silt
5.5
8
10
Penetration CG
0.1 m
0.2 m
0.3 m
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
SNUM Max Penetration CG
5.5 0.92 m
8 1.33 m
10 1.64 m
Min. impact velocity 64 m/s
Max. impact velocity 200 m/s
Min. impact angle 46 deg
Max. impact angle 82 deg

105mm M456 HEAT

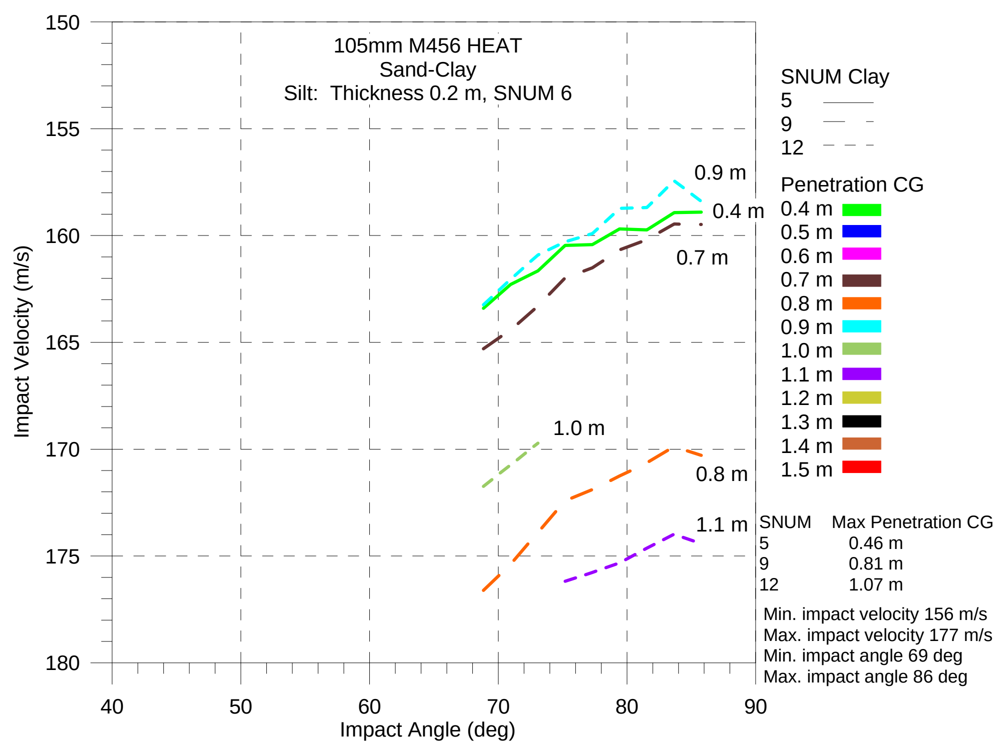
Sand-Silt

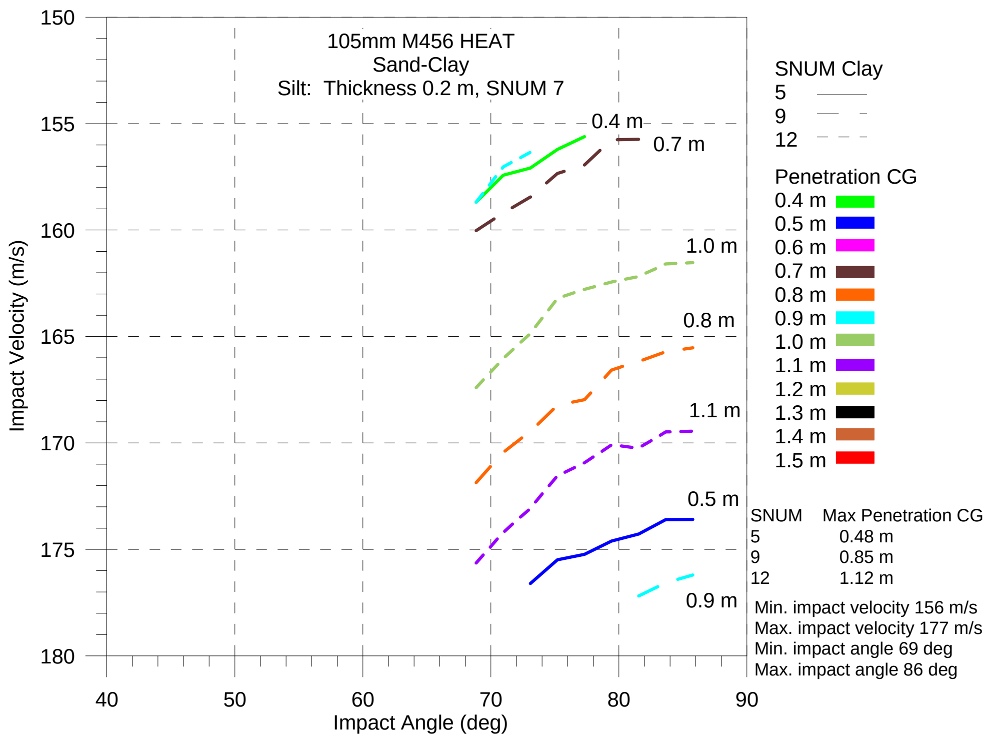




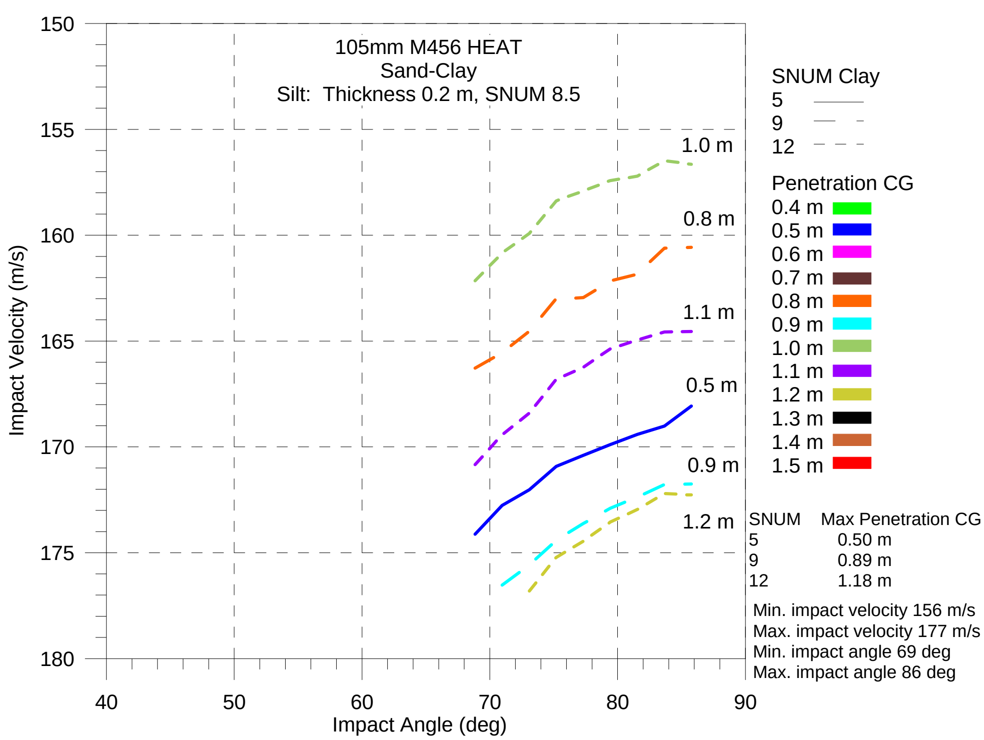

105mm M456 HEAT
Sand-Silt
Sand: Thickness 0.2 m, SNUM 8.5
Impact Velocity (m/s)
Impact Angle (deg)
150
155
160
165
170
175
180
40
50
60
70
80
90
0.7 m
0.5 m
0.9 m
0.8 m
1.0 m
SNUM Silt
5.5
8
10
Penetration CG
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
1.3 m
1.4 m
1.5 m
SNUM Max Penetration CG
5.5 0.55 m
8 0.79 m
10 0.98 m
Min. impact velocity 156 m/s
Max. impact velocity 177 m/s
Min. impact angle 69 deg
Max. impact angle 86 deg

Sand-Clay


105mm M456 HEAT
Sand-Clay
Silt: Thickness 0.2 m, SNUM 6
Impact Velocity (m/s)
Impact Angle (deg)
150
155
160
165
170
175
180
40
50
60
70
80
90
0.9 m
0.4 m
0.7 m
1.0 m
0.8 m
1.1 m
SNUM Clay
5
9
12
Penetration CG
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
1.3 m
1.4 m
1.5 m
SNUM Max Penetration CG
5 0.46 m
9 0.81 m
12 1.07 m
Min. impact velocity 156 m/s
Max. impact velocity 177 m/s
Min. impact angle 69 deg
Max. impact angle 86 deg

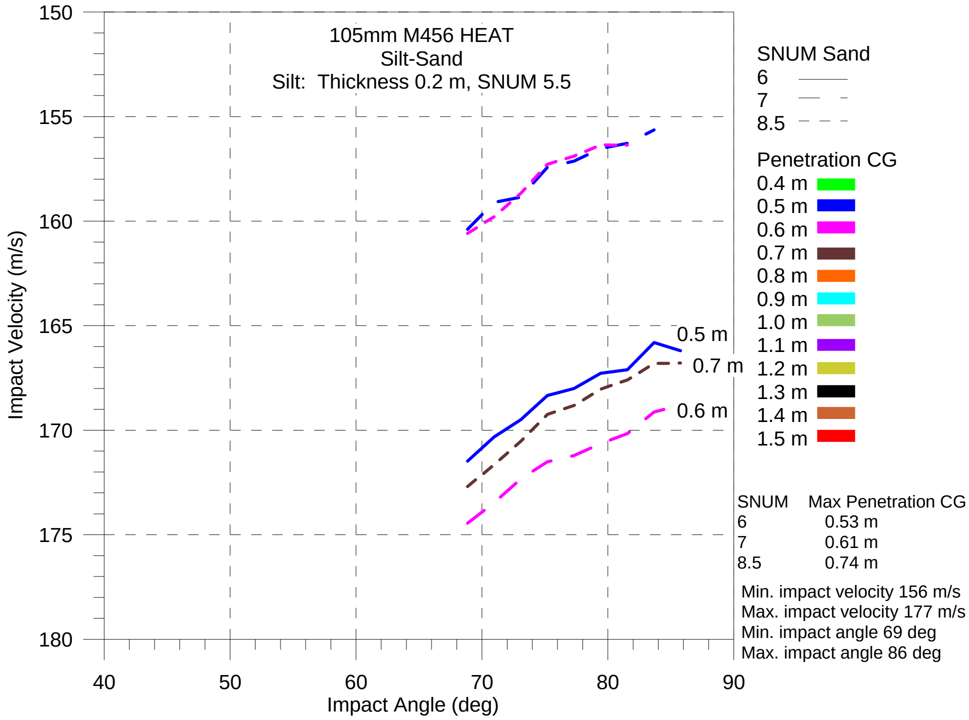


105mm M456 HEAT
Sand-Clay
Silt: Thickness 0.2 m, SNUM 7
Impact Velocity (m/s)
Impact Angle (deg)
0.4 m
0.7 m
1.0 m
0.8 m
1.1 m
0.5 m
0.9 m
SNUM Clay
5
9
12
Penetration CG
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
1.3 m
1.4 m
1.5 m
SNUM Max Penetration CG
5 0.48 m
9 0.85 m
12 1.12 m
Min. impact velocity 156 m/s
Max. impact velocity 177 m/s
Min. impact angle 69 deg
Max. impact angle 86 deg

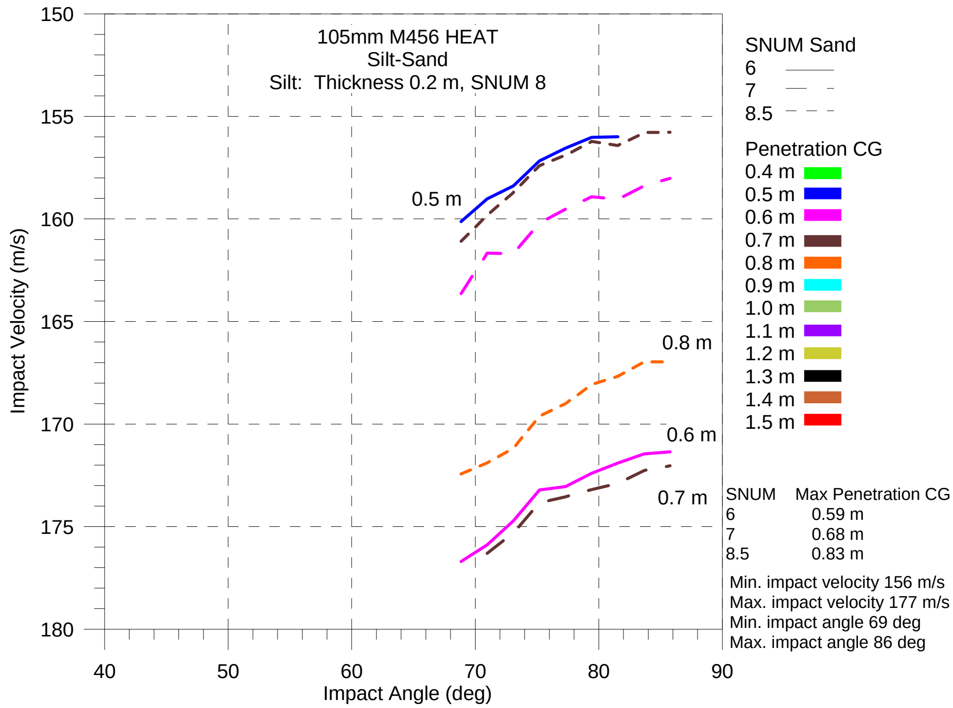


105mm M456 HEAT
Sand-Clay
Silt: Thickness 0.2 m, SNUM 8.5
Impact Velocity (m/s)
Impact Angle (deg)
1.0 m
0.8 m
1.1 m
0.5 m
0.9 m
1.2 m
SNUM Clay
5
9
12
Penetration CG
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
1.3 m
1.4 m
1.5 m
SNUM Max Penetration CG
5 0.50 m
9 0.89 m
12 1.18 m
Min. impact velocity 156 m/s
Max. impact velocity 177 m/s
Min. impact angle 69 deg
Max. impact angle 86 deg

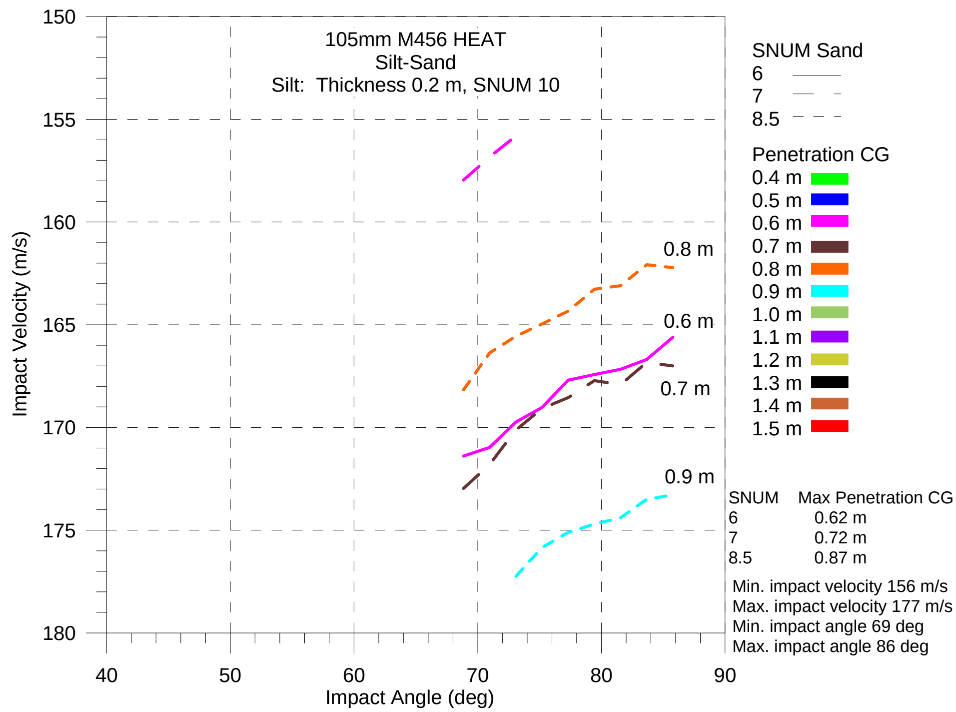
Silt-Sand



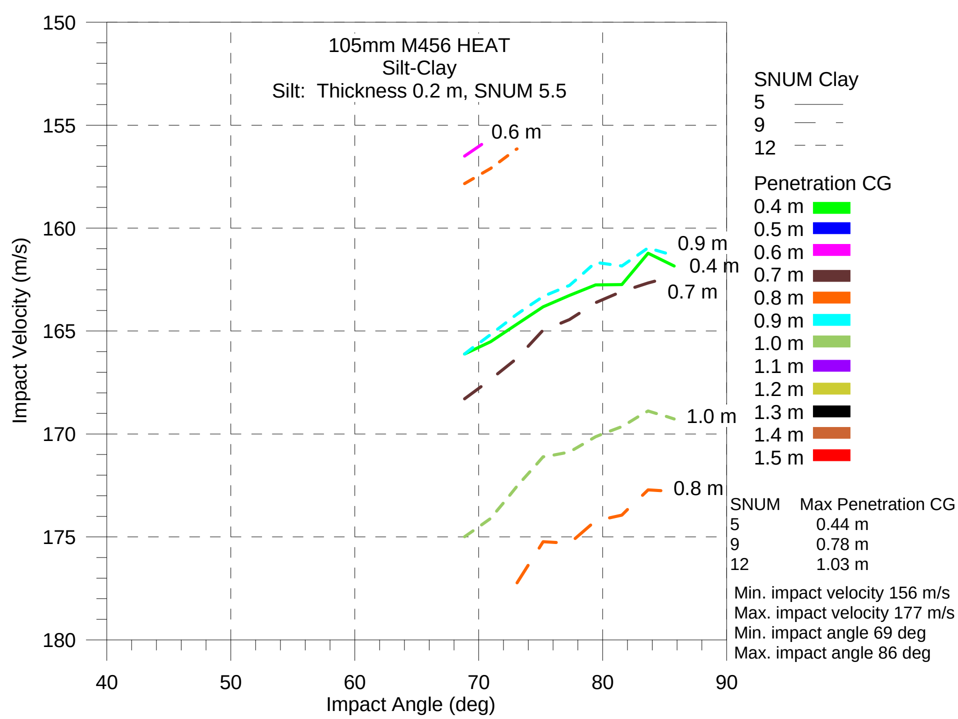
105mm M456 HEAT
Silt-Sand
Silt: Thickness 0.2 m, SNUM 5.5
Impact Velocity (m/s)
Impact Angle (deg)
0.5 m
0.7 m
0.6 m
SNUM Sand
6
7
8.5
Penetration CG
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
1.3 m
1.4 m
1.5 m
SNUM Max Penetration CG
6 0.53 m
7 0.61 m
8.5 0.74 m
Min. impact velocity 156 m/s
Max. impact velocity 177 m/s
Min. impact angle 69 deg
Max. impact angle 86 deg

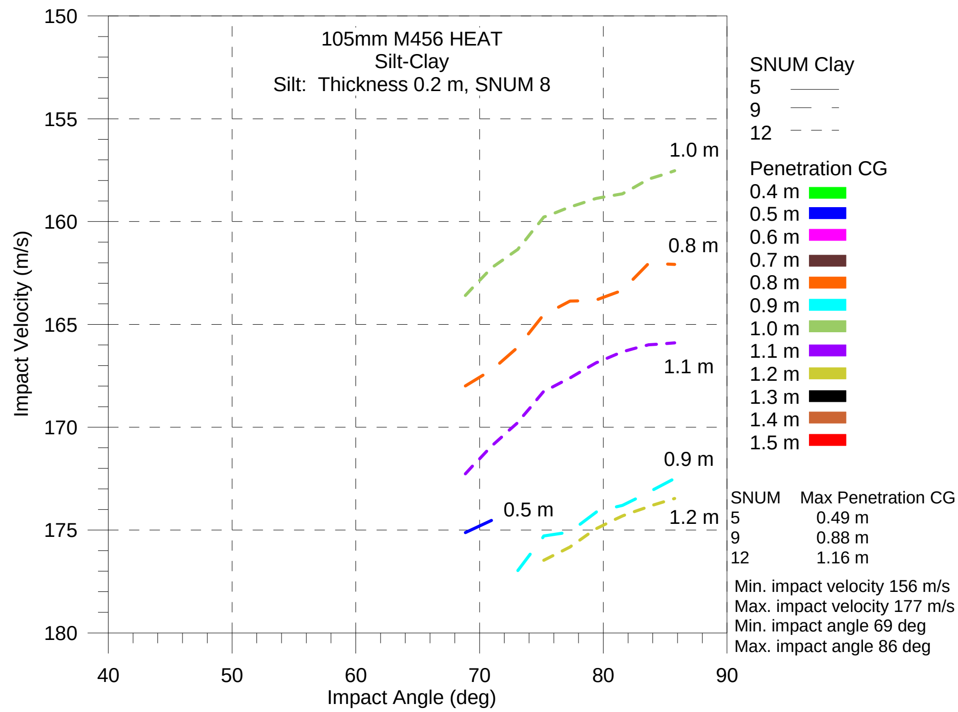


105mm M456 HEAT
Silt-Sand
Silt: Thickness 0.2 m, SNUM 8
Impact Velocity (m/s)
Impact Angle (deg)
0.5 m
0.8 m
0.6 m
0.7 m
SNUM Sand
6
7
8.5
Penetration CG
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
1.3 m
1.4 m
1.5 m
SNUM Max Penetration CG
6 0.59 m
7 0.68 m
8.5 0.83 m
Min. impact velocity 156 m/s
Max. impact velocity 177 m/s
Min. impact angle 69 deg
Max. impact angle 86 deg

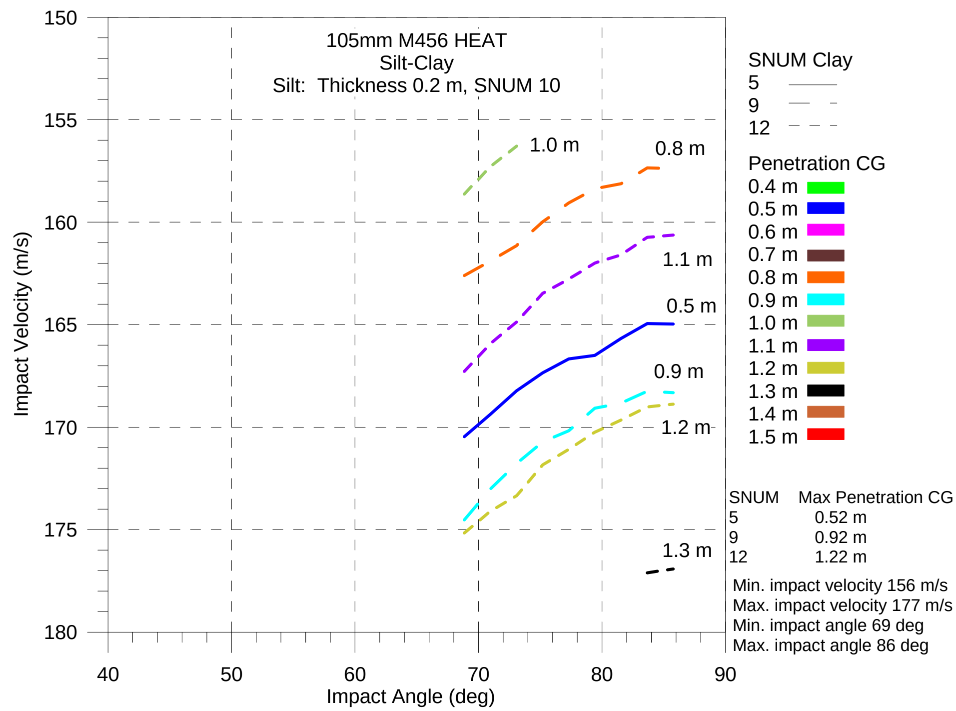

105mm M456 HEAT
Silt-Sand
Silt: Thickness 0.2 m, SNUM 10
Impact Velocity (m/s)
Impact Angle (deg)
0.8 m
0.6 m
0.7 m
0.9 m
SNUM Sand
6
7
8.5
Penetration CG
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
1.3 m
1.4 m
1.5 m
SNUM Max Penetration CG
6 0.62 m
7 0.72 m
8.5 0.87 m
Min. impact velocity 156 m/s
Max. impact velocity 177 m/s
Min. impact angle 69 deg
Max. impact angle 86 deg

Silt-Clay


105mm M456 HEAT
Silt-Clay
Silt: Thickness 0.2 m, SNUM 5.5
Impact Velocity (m/s)
Impact Angle (deg)
0.6 m
0.9 m
0.4 m
0.7 m
1.0 m
0.8 m
SNUM Clay
5
9
12
Penetration CG
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
1.3 m
1.4 m
1.5 m
SNUM Max Penetration CG
5 0.44 m
9 0.78 m
12 1.03 m
Min. impact velocity 156 m/s
Max. impact velocity 177 m/s
Min. impact angle 69 deg
Max. impact angle 86 deg

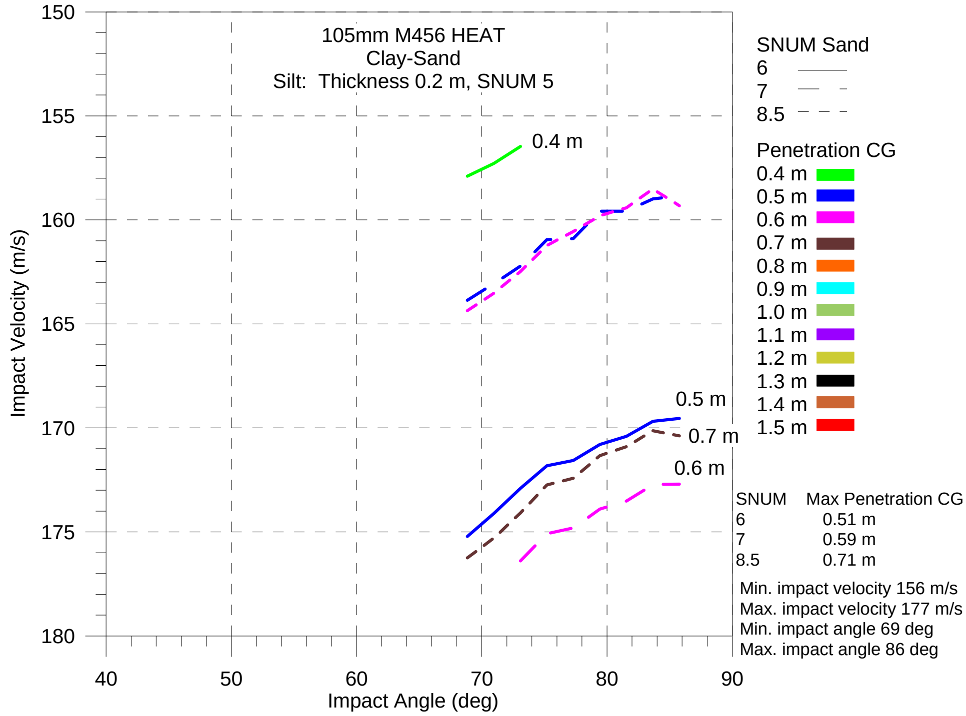


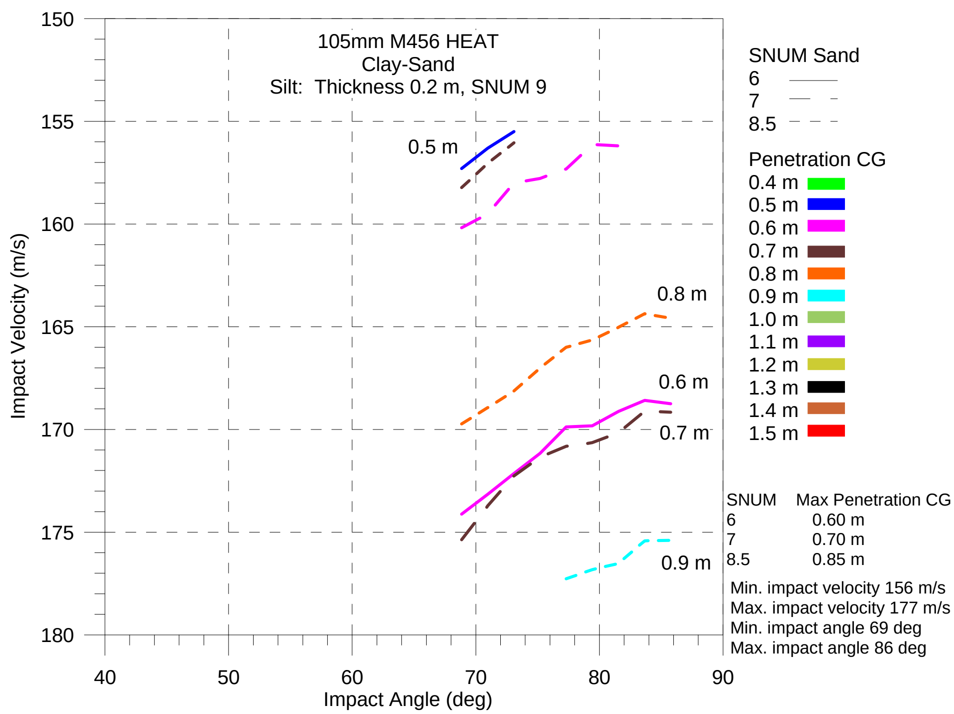
105mm M456 HEAT
Silt-Clay
Silt: Thickness 0.2 m, SNUM 8
Impact Velocity (m/s)
Impact Angle (deg)
1.0 m
0.8 m
1.1 m
0.9 m
0.5 m
1.2 m
SNUM Clay
5
9
12
Penetration CG
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
1.3 m
1.4 m
1.5 m
SNUM Max Penetration CG
5 0.49 m
9 0.88 m
12 1.16 m
Min. impact velocity 156 m/s
Max. impact velocity 177 m/s
Min. impact angle 69 deg
Max. impact angle 86 deg

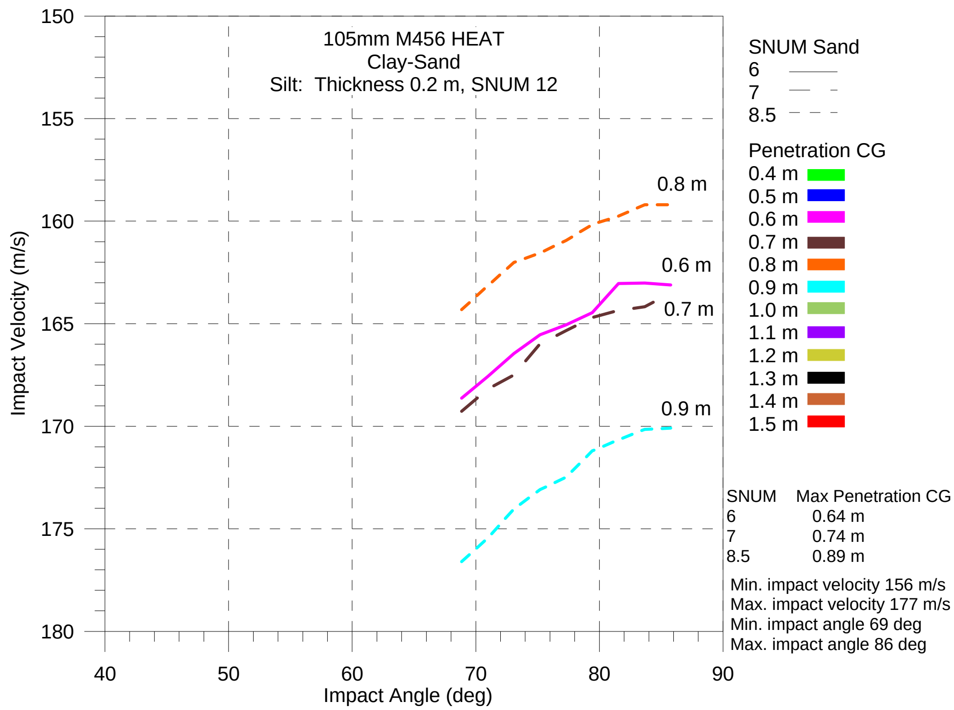


105mm M456 HEAT
Silt-Clay
Silt: Thickness 0.2 m, SNUM 10
Impact Velocity (m/s)
Impact Angle (deg)
1.0 m
0.8 m
1.1 m
0.5 m
0.9 m
1.2 m
1.3 m
SNUM Clay
5
9
12
Penetration CG
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
1.3 m
1.4 m
1.5 m
SNUM Max Penetration CG
5 0.52 m
9 0.92 m
12 1.22 m
Min. impact velocity 156 m/s
Max. impact velocity 177 m/s
Min. impact angle 69 deg
Max. impact angle 86 deg

Clay-Sand

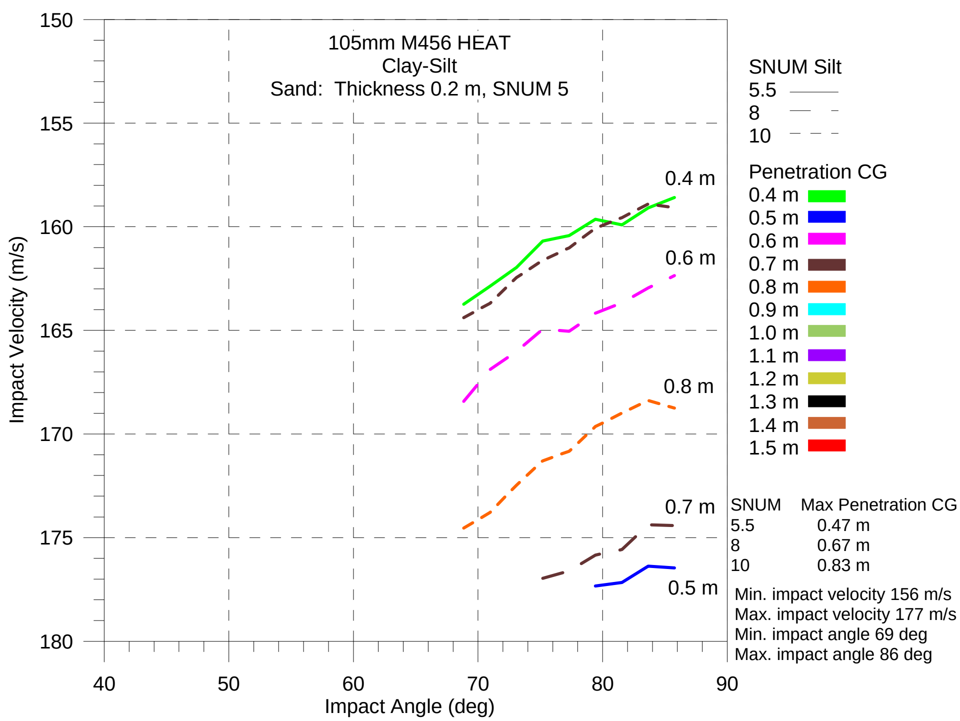

105mm M456 HEAT
Clay-Sand
Silt: Thickness 0.2 m, SNUM 5
0.4 m
0.5 m
0.7 m
0.6 m
Impact Velocity (m/s)
Impact Angle (deg)
SNUM Sand
6
7
8.5
Penetration CG
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
1.3 m
1.4 m
1.5 m
SNUM Max Penetration CG
6 0.51 m
7 0.59 m
8.5 0.71 m
Min. impact velocity 156 m/s
Max. impact velocity 177 m/s
Min. impact angle 69 deg
Max. impact angle 86 deg


105mm M456 HEAT
Clay-Sand
Silt: Thickness 0.2 m, SNUM 9
0.5 m
0.8 m
0.6 m
0.7 m
0.9 m
Impact Velocity (m/s)
Impact Angle (deg)
SNUM Sand
6
7
8.5
Penetration CG
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
1.3 m
1.4 m
1.5 m
SNUM Max Penetration CG
6 0.60 m
7 0.70 m
8.5 0.85 m
Min. impact velocity 156 m/s
Max. impact velocity 177 m/s
Min. impact angle 69 deg
Max. impact angle 86 deg

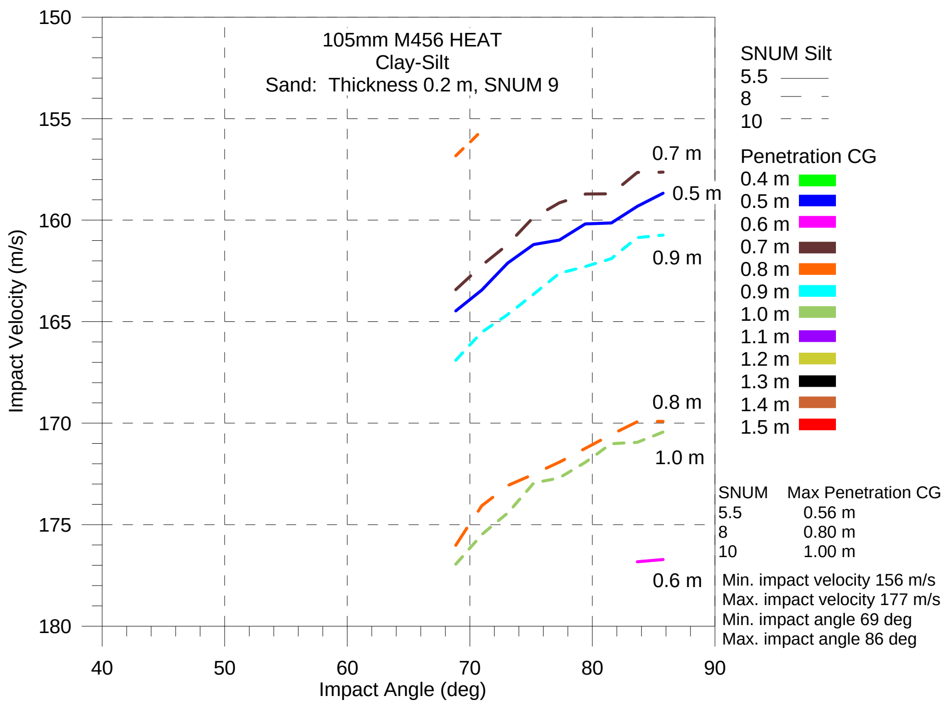


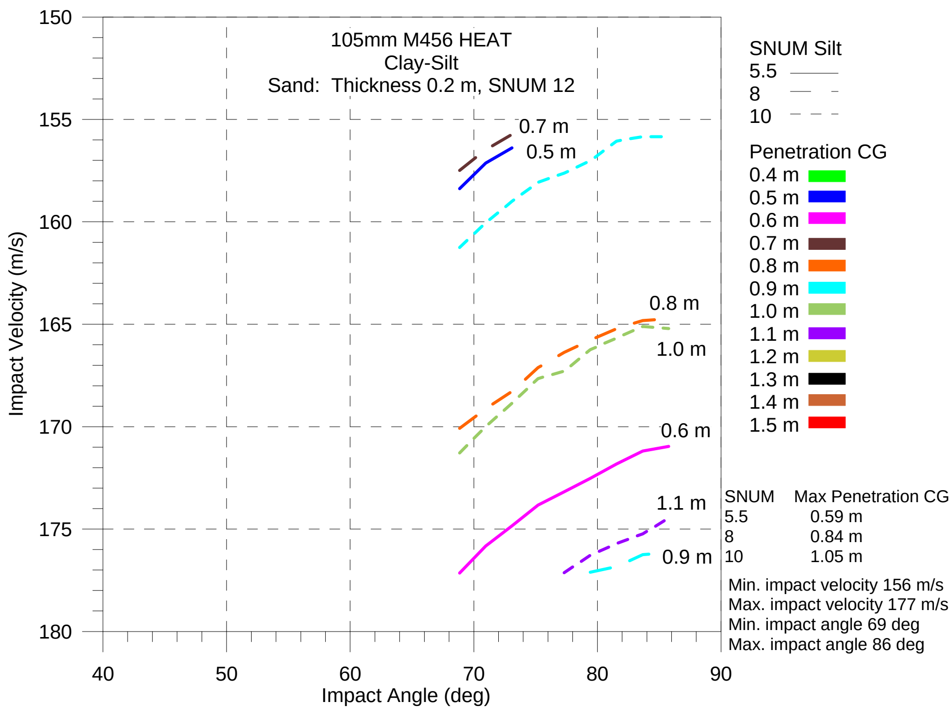
105mm M456 HEAT
Clay-Sand
Silt: Thickness 0.2 m, SNUM 12
Impact Velocity (m/s)
Impact Angle (deg)
SNUM Sand
6
7
8.5
Penetration CG
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
1.3 m
1.4 m
1.5 m
SNUM Max Penetration CG
6 0.64 m
7 0.74 m
8.5 0.89 m
Min. impact velocity 156 m/s
Max. impact velocity 177 m/s
Min. impact angle 69 deg
Max. impact angle 86 deg

Clay-Silt



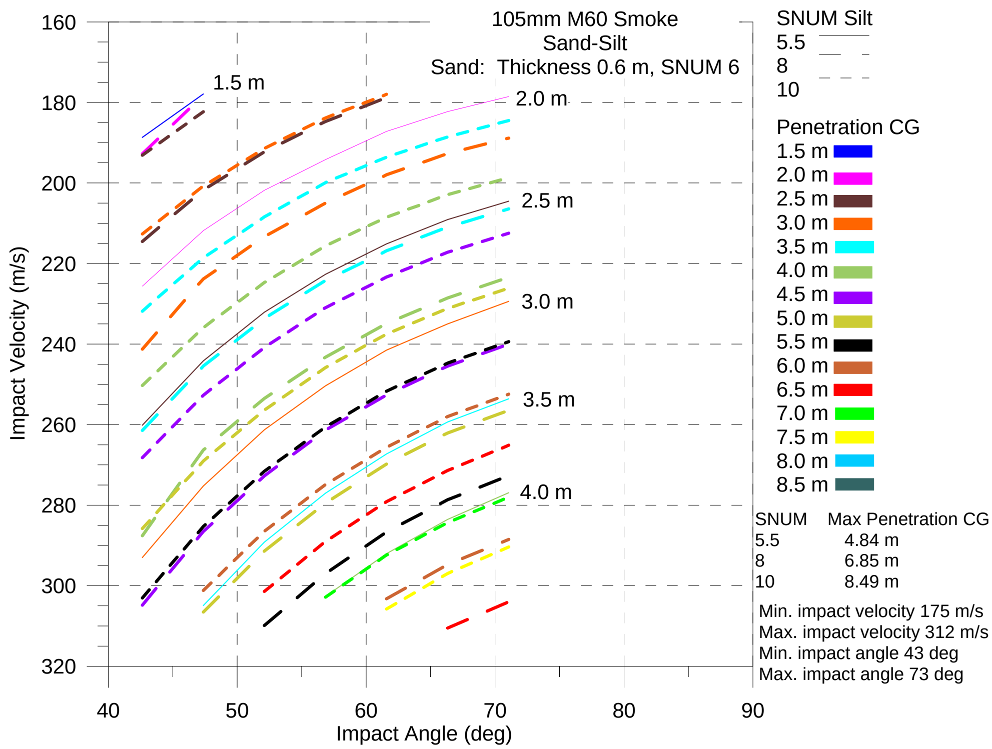
105mm M456 HEAT
Clay-Silt
Sand: Thickness 0.2 m, SNUM 5
Impact Velocity (m/s)
Impact Angle (deg)
SNUM Silt
5.5
8
10
Penetration CG
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
1.3 m
1.4 m
1.5 m
SNUM Max Penetration CG
5.5 0.47 m
8 0.67 m
10 0.83 m
Min. impact velocity 156 m/s
Max. impact velocity 177 m/s
Min. impact angle 69 deg
Max. impact angle 86 deg

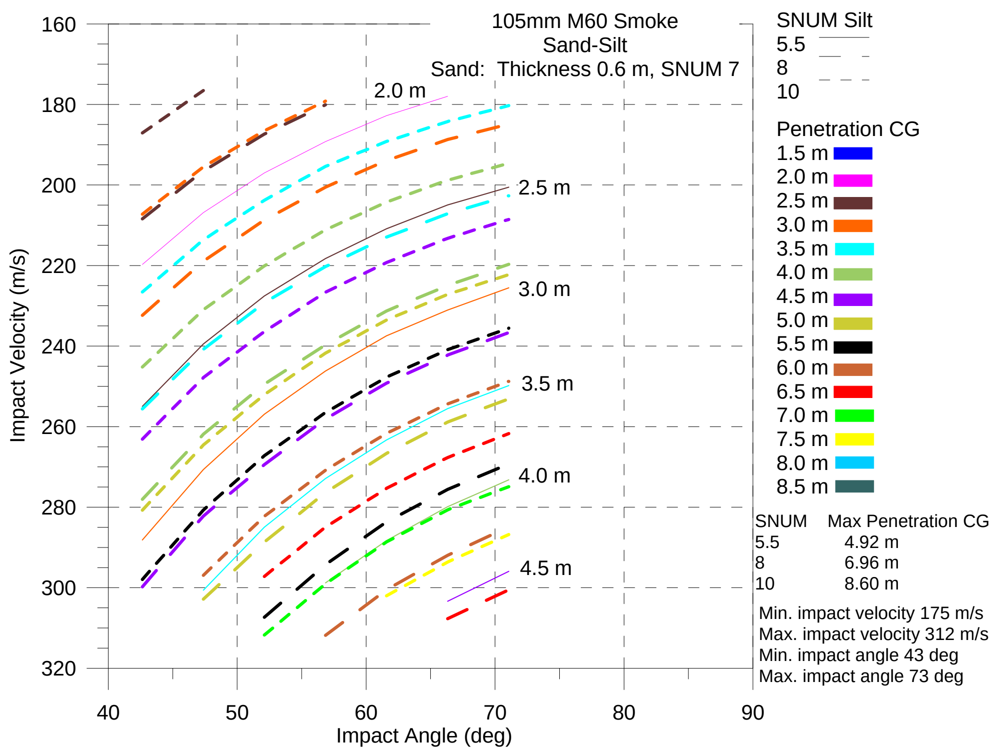

105mm M456 HEAT
Clay-Silt
Sand: Thickness 0.2 m, SNUM 9
Impact Velocity (m/s)
Impact Angle (deg)
0.7 m
0.5 m
0.9 m
0.8 m
1.0 m
0.6 m
SNUM Silt
5.5
8
10
Penetration CG
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
1.3 m
1.4 m
1.5 m
SNUM Max Penetration CG
5.5 0.56 m
8 0.80 m
10 1.00 m
Min. impact velocity 156 m/s
Max. impact velocity 177 m/s
Min. impact angle 69 deg
Max. impact angle 86 deg

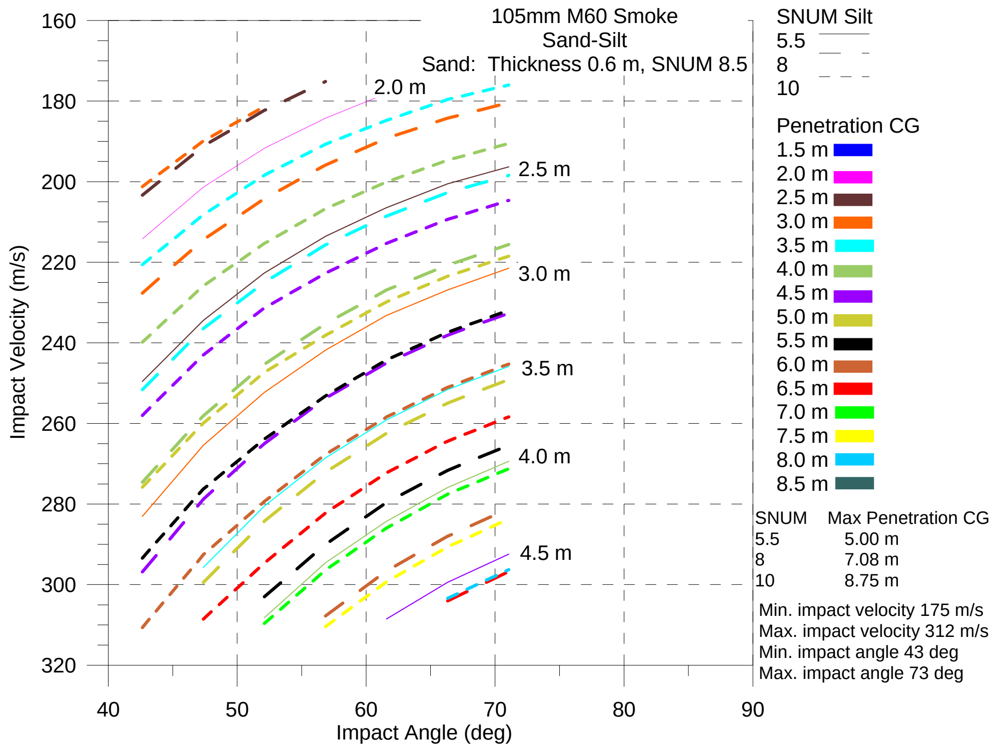

105mm M456 HEAT
Clay-Silt
Sand: Thickness 0.2 m, SNUM 12
Impact Velocity (m/s)
Impact Angle (deg)
0.7 m
0.5 m
0.8 m
1.0 m
0.6 m
1.1 m
0.9 m
SNUM Silt
5.5
8
10
Penetration CG
0.4 m
0.5 m
0.6 m
0.7 m
0.8 m
0.9 m
1.0 m
1.1 m
1.2 m
1.3 m
1.4 m
1.5 m
SNUM Max Penetration CG
5.5 0.59 m
8 0.84 m
10 1.05 m
Min. impact velocity 156 m/s
Max. impact velocity 177 m/s
Min. impact angle 69 deg
Max. impact angle 86 deg

105mm M60 Smoke

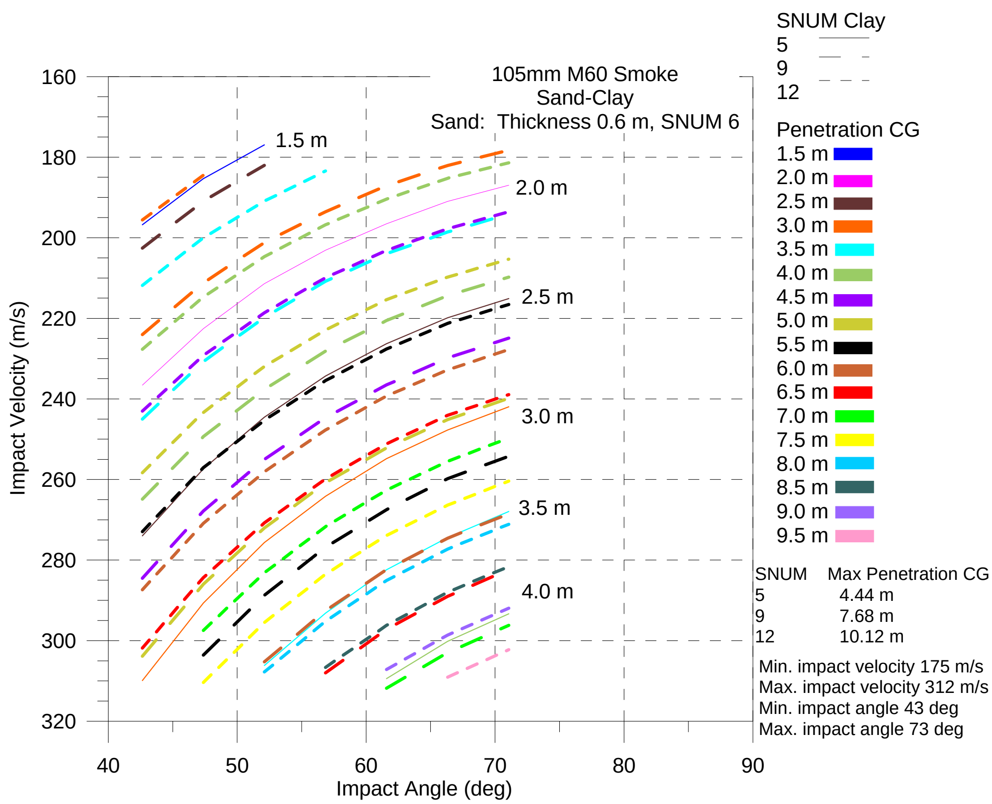
Sand-Silt

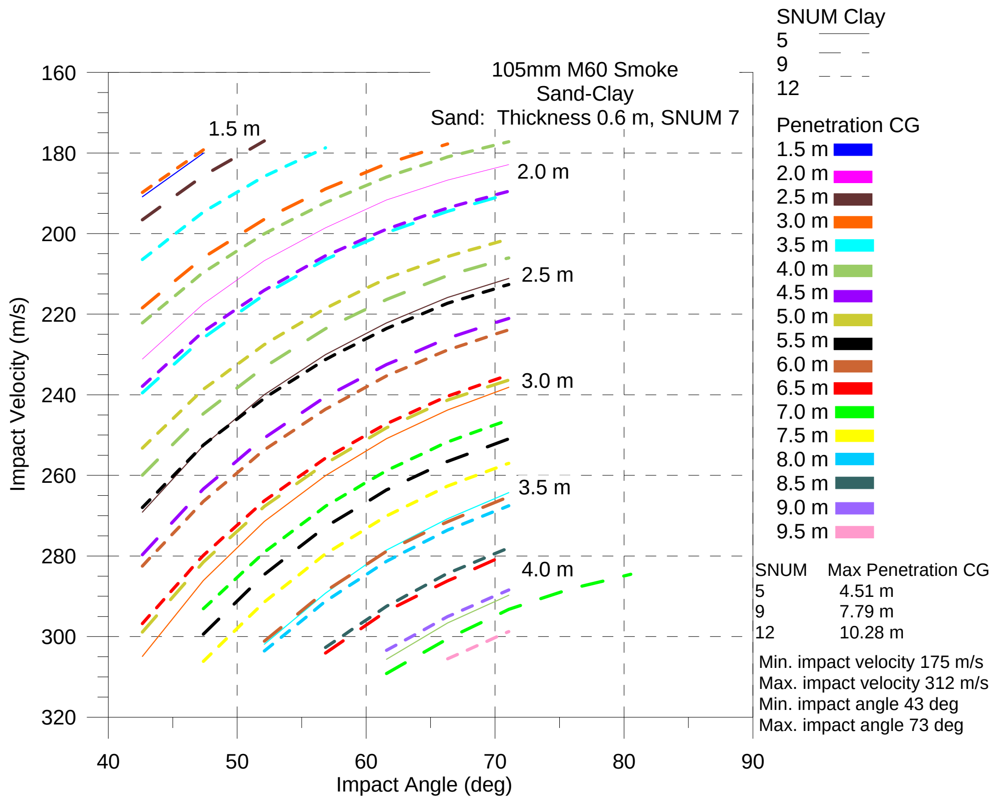


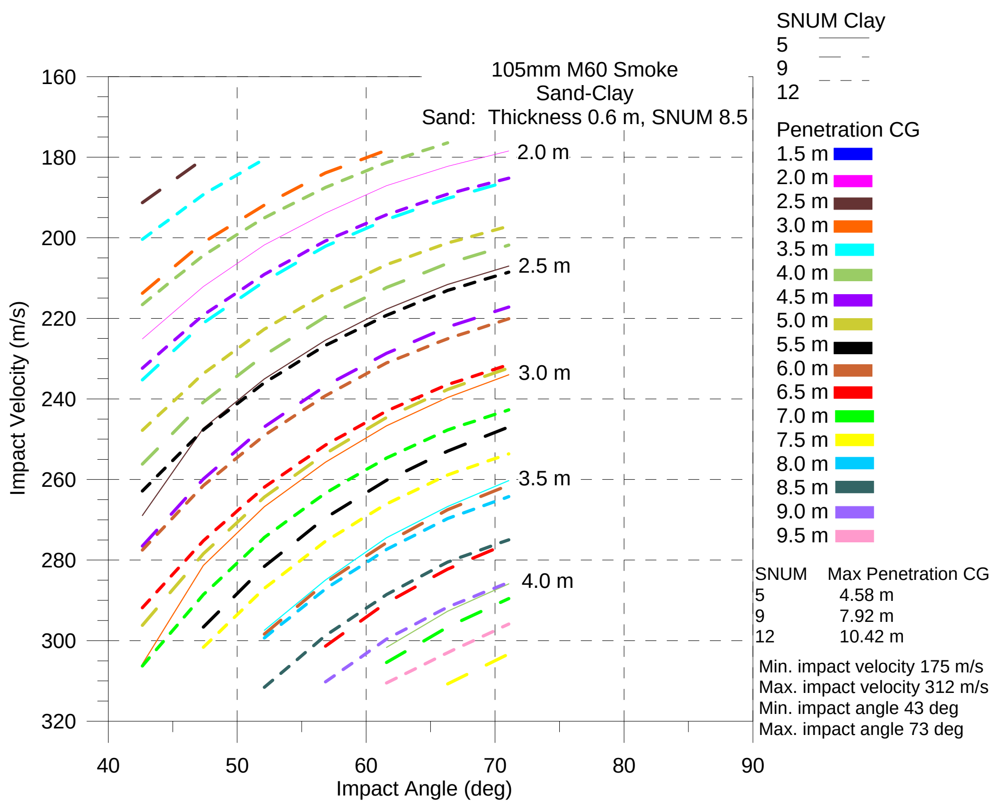



105mm M60 Smoke
Sand-Silt
Sand: Thickness 0.6 m, SNUM 8.5
Impact Velocity (m/s)
Impact Angle (deg)
2.0 m
2.5 m
3.0 m
3.5 m
4.0 m
4.5 m
SNUM Silt
5.5
8
10
Penetration CG
1.5 m
2.0 m
2.5 m
3.0 m
3.5 m
4.0 m
4.5 m
5.0 m
5.5 m
6.0 m
6.5 m
7.0 m
7.5 m
8.0 m
8.5 m
SNUM Max Penetration CG
5.5 5.00 m
8 7.08 m
10 8.75 m
Min. impact velocity 175 m/s
Max. impact velocity 312 m/s
Min. impact angle 43 deg
Max. impact angle 73 deg

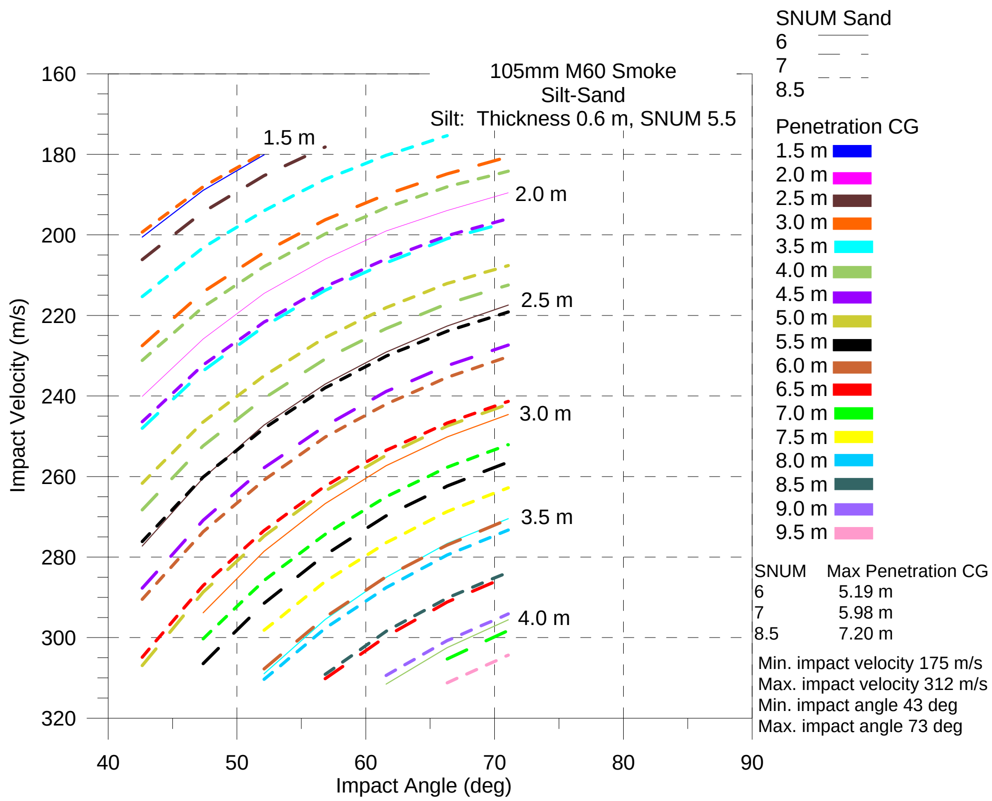
Sand-Clay


105mm M60 Smoke
Sand-Clay
Sand: Thickness 0.6 m, SNUM 6
Impact Velocity (m/s)
Impact Angle (deg)
1.5 m
2.0 m
2.5 m
3.0 m
3.5 m
4.0 m
SNUM Clay
5
9
12
Penetration CG
1.5 m
2.0 m
2.5 m
3.0 m
3.5 m
4.0 m
4.5 m
5.0 m
5.5 m
6.0 m
6.5 m
7.0 m
7.5 m
8.0 m
8.5 m
9.0 m
9.5 m
SNUM Max Penetration CG
5 4.44 m
9 7.68 m
12 10.12 m
Min. impact velocity 175 m/s
Max. impact velocity 312 m/s
Min. impact angle 43 deg
Max. impact angle 73 deg

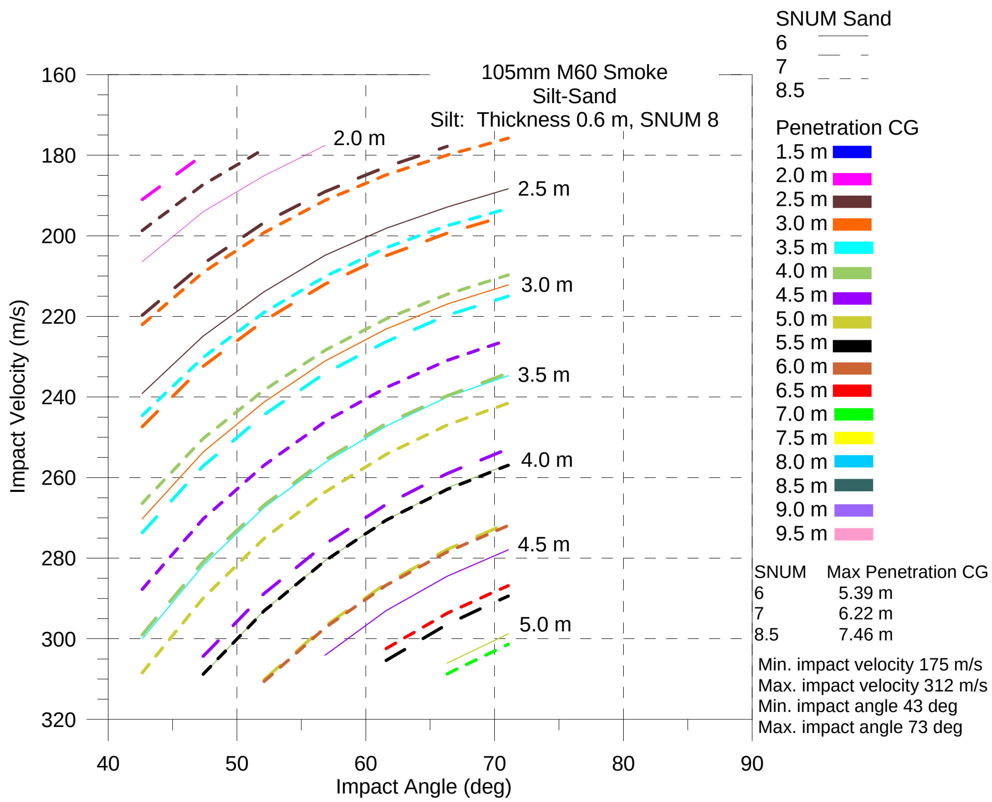

105mm M60 Smoke
Sand-Clay
Sand: Thickness 0.6 m, SNUM 7
1.5 m
2.0 m
2.5 m
3.0 m
3.5 m
4.0 m
Impact Velocity (m/s)
Impact Angle (deg)
160
180
200
220
240
260
280
300
320
40
50
60
70
80
90
SNUM Clay
5
9
12
Penetration CG
1.5 m
2.0 m
2.5 m
3.0 m
3.5 m
4.0 m
4.5 m
5.0 m
5.5 m
6.0 m
6.5 m
7.0 m
7.5 m
8.0 m
8.5 m
9.0 m
9.5 m
SNUM Max Penetration CG
5 4.51 m
9 7.79 m
12 10.28 m
Min. impact velocity 175 m/s
Max. impact velocity 312 m/s
Min. impact angle 43 deg
Max. impact angle 73 deg


105mm M60 Smoke
Sand-Clay
Sand: Thickness 0.6 m, SNUM 8.5
2.0 m
2.5 m
3.0 m
3.5 m
4.0 m
Impact Velocity (m/s)
Impact Angle (deg)
160
180
200
220
240
260
280
300
320
40
50
60
70
80
90
SNUM Clay
5
9
12
Penetration CG
1.5 m
2.0 m
2.5 m
3.0 m
3.5 m
4.0 m
4.5 m
5.0 m
5.5 m
6.0 m
6.5 m
7.0 m
7.5 m
8.0 m
8.5 m
9.0 m
9.5 m
SNUM Max Penetration CG
5 4.58 m
9 7.92 m
12 10.42 m
Min. impact velocity 175 m/s
Max. impact velocity 312 m/s
Min. impact angle 43 deg
Max. impact angle 73 deg

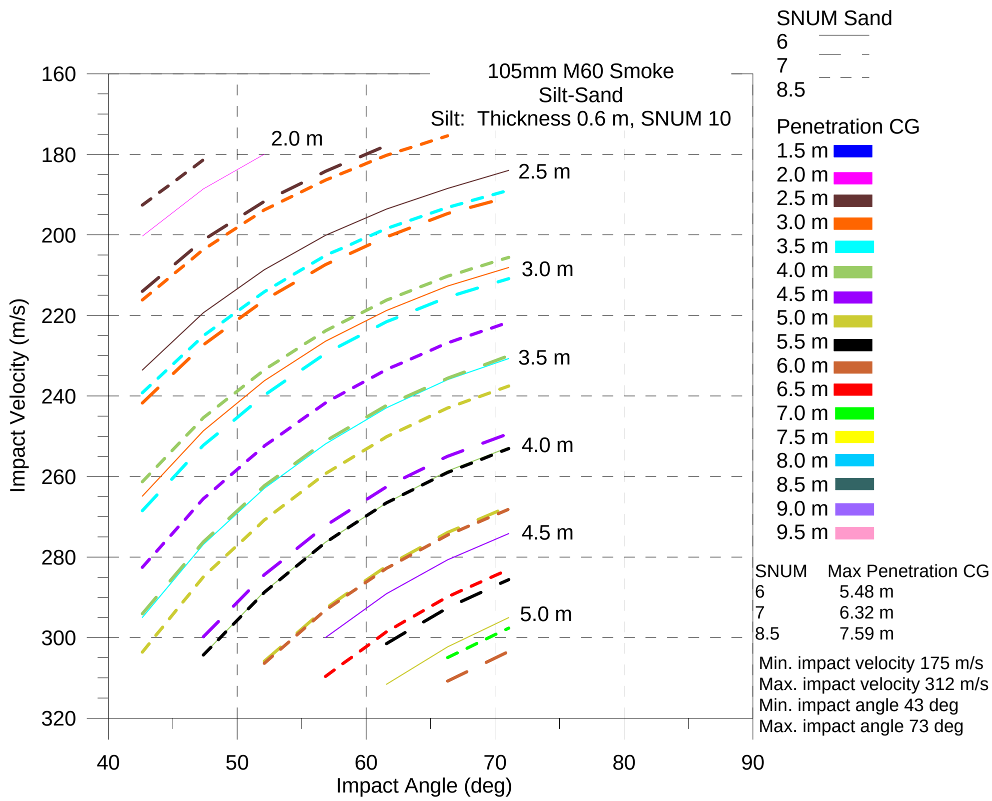
Silt-Sand



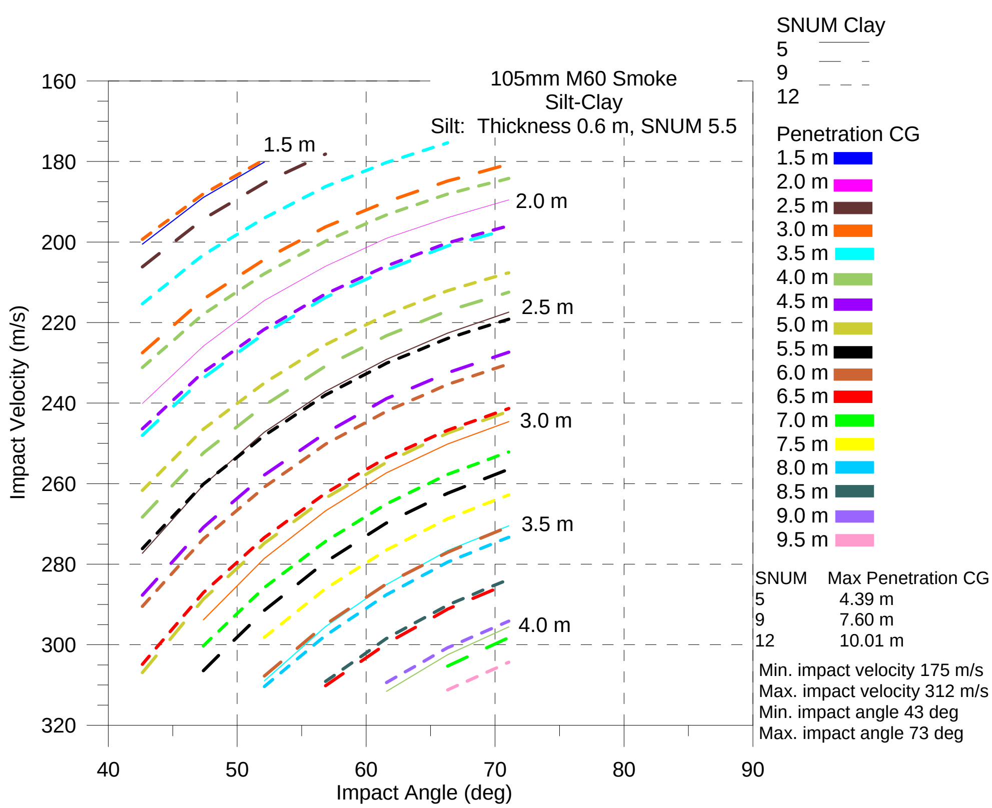
105mm M60 Smoke
Silt-Sand
Silt: Thickness 0.6 m, SNUM 5.5
1.5 m
2.0 m
2.5 m
3.0 m
3.5 m
4.0 m
Impact Velocity (m/s)
Impact Angle (deg)
160
180
200
220
240
260
280
300
320
40
50
60
70
80
90
SNUM Sand
6
7
8.5
Penetration CG
1.5 m
2.0 m
2.5 m
3.0 m
3.5 m
4.0 m
4.5 m
5.0 m
5.5 m
6.0 m
6.5 m
7.0 m
7.5 m
8.0 m
8.5 m
9.0 m
9.5 m
SNUM Max Penetration CG
6 5.19 m
7 5.98 m
8.5 7.20 m
Min. impact velocity 175 m/s
Max. impact velocity 312 m/s
Min. impact angle 43 deg
Max. impact angle 73 deg

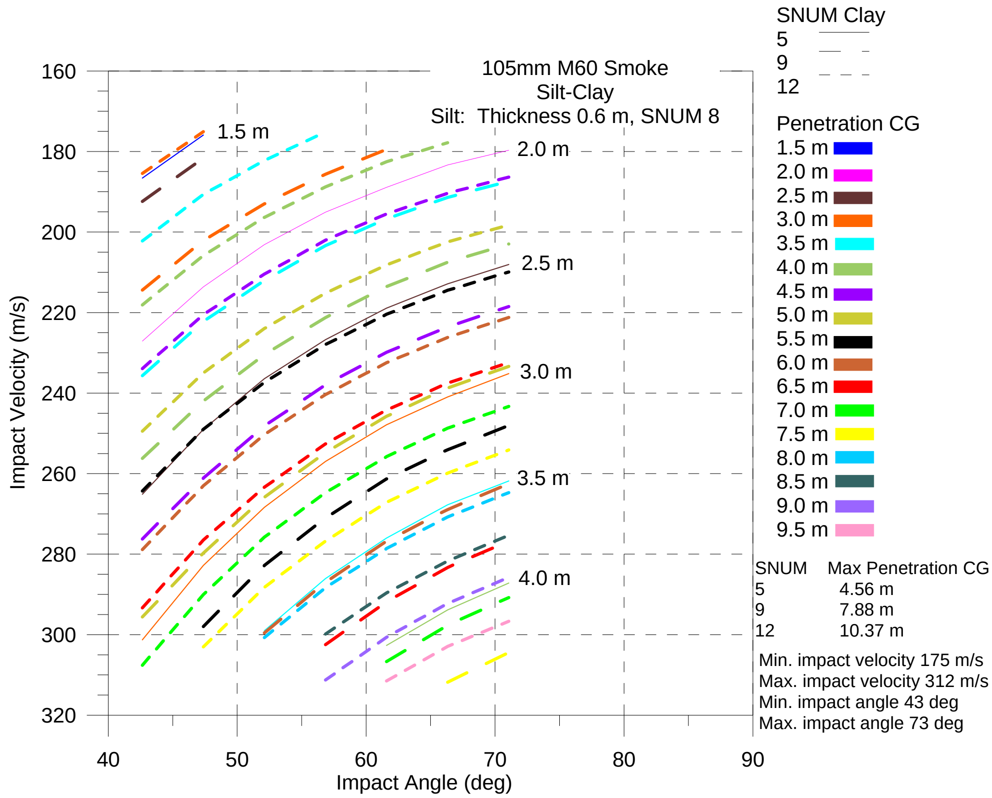


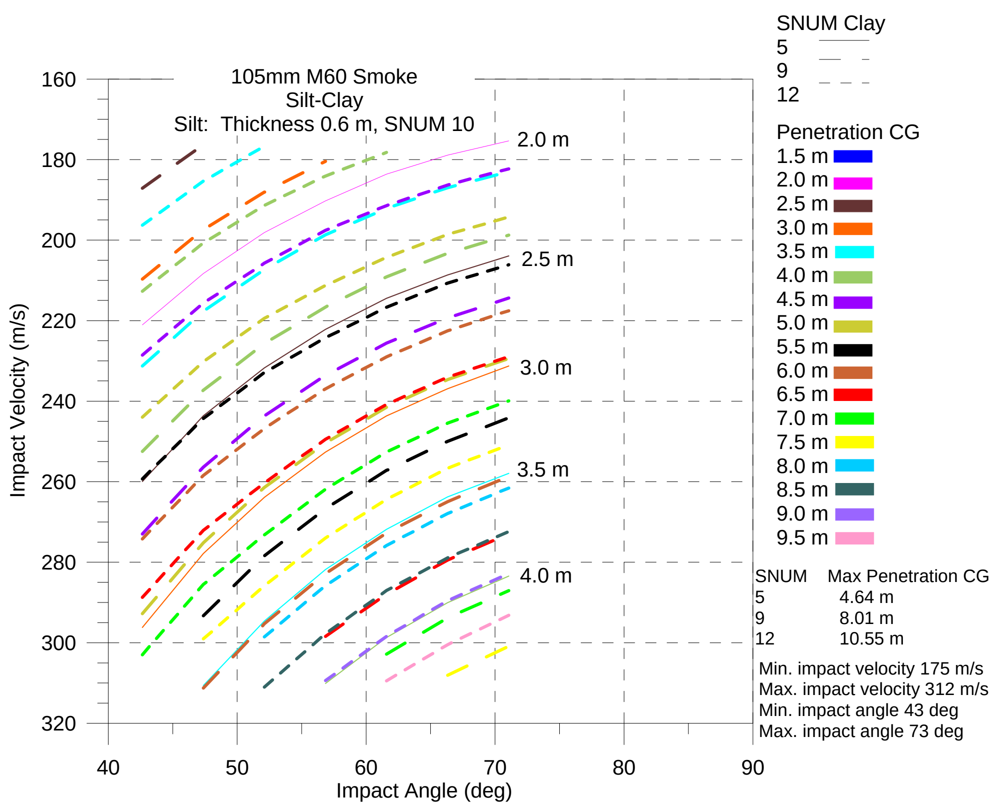
105mm M60 Smoke
Silt-Sand
Silt: Thickness 0.6 m, SNUM 8
2.0 m
2.5 m
3.0 m
3.5 m
4.0 m
4.5 m
5.0 m
Impact Velocity (m/s)
Impact Angle (deg)
160
180
200
220
240
260
280
300
320
40
50
60
70
80
90
SNUM Sand
6
7
8.5
Penetration CG
1.5 m
2.0 m
2.5 m
3.0 m
3.5 m
4.0 m
4.5 m
5.0 m
5.5 m
6.0 m
6.5 m
7.0 m
7.5 m
8.0 m
8.5 m
9.0 m
9.5 m
SNUM Max Penetration CG
6 5.39 m
7 6.22 m
8.5 7.46 m
Min. impact velocity 175 m/s
Max. impact velocity 312 m/s
Min. impact angle 43 deg
Max. impact angle 73 deg


SNUM Sand
6
7
8.5
105mm M60 Smoke
Silt-Sand
Silt: Thickness 0.6 m, SNUM 10
Penetration CG
1.5 m
2.0 m
2.5 m
3.0 m
3.5 m
4.0 m
4.5 m
5.0 m
5.5 m
6.0 m
6.5 m
7.0 m
7.5 m
8.0 m
8.5 m
9.0 m
9.5 m
SNUM Max Penetration CG
6 5.48 m
7 6.32 m
8.5 7.59 m
Min. impact velocity 175 m/s
Max. impact velocity 312 m/s
Min. impact angle 43 deg
Max. impact angle 73 deg
Impact Velocity (m/s)
Impact Angle (deg)

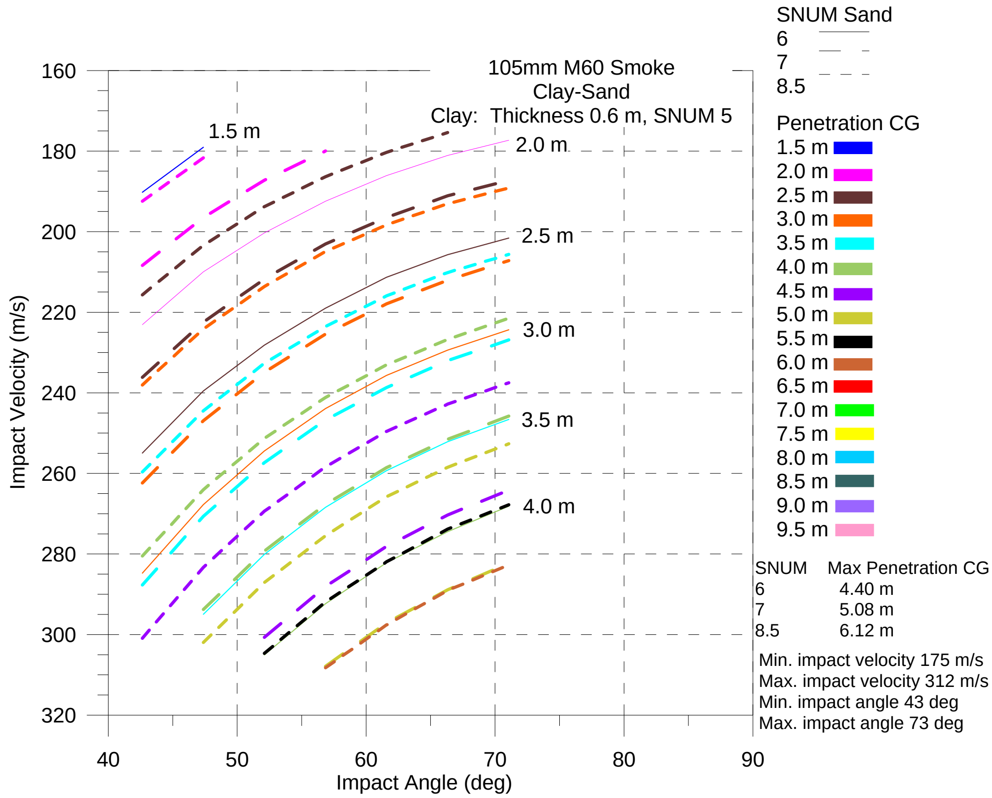
Silt-Clay


SNUM Clay
5
9
12
105mm M60 Smoke
Silt-Clay
Silt: Thickness 0.6 m, SNUM 5.5
Penetration CG
1.5 m
2.0 m
2.5 m
3.0 m
3.5 m
4.0 m
4.5 m
5.0 m
5.5 m
6.0 m
6.5 m
7.0 m
7.5 m
8.0 m
8.5 m
9.0 m
9.5 m
SNUM Max Penetration CG
5 4.39 m
9 7.60 m
12 10.01 m
Min. impact velocity 175 m/s
Max. impact velocity 312 m/s
Min. impact angle 43 deg
Max. impact angle 73 deg
Impact Velocity (m/s)
Impact Angle (deg)

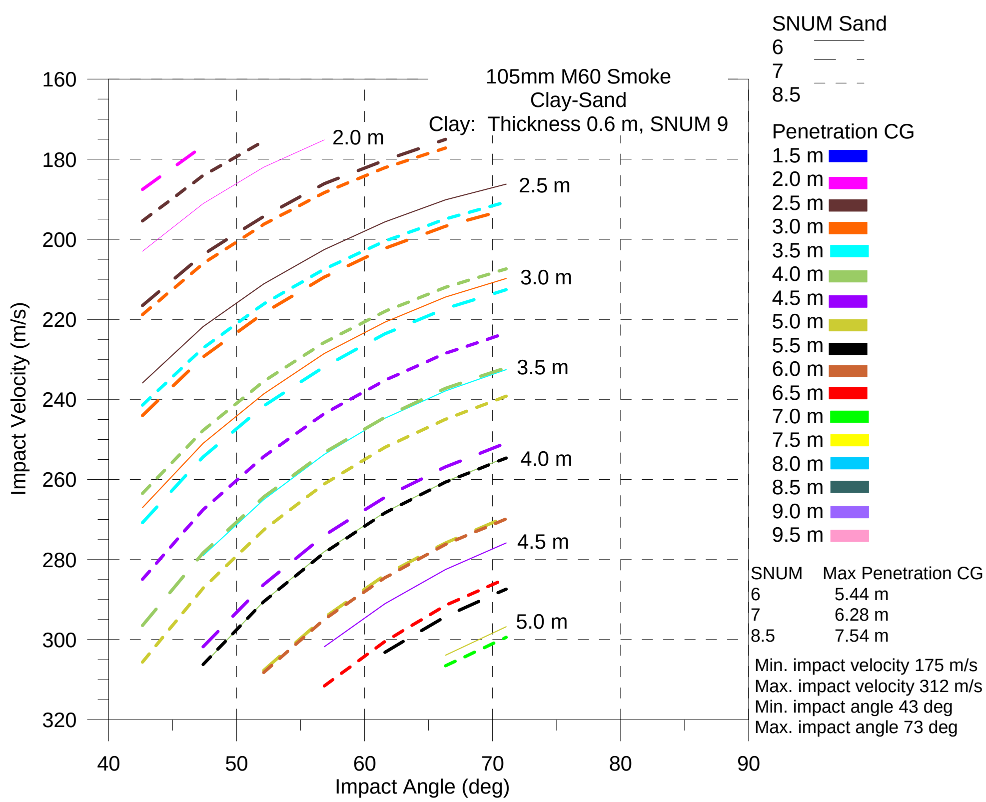

105mm M60 Smoke
Silt-Clay
Silt: Thickness 0.6 m, SNUM 8
Impact Velocity (m/s)
Impact Angle (deg)
1.5 m
2.0 m
2.5 m
3.0 m
3.5 m
4.0 m
SNUM Clay
5
9
12
Penetration CG
1.5 m
2.0 m
2.5 m
3.0 m
3.5 m
4.0 m
4.5 m
5.0 m
5.5 m
6.0 m
6.5 m
7.0 m
7.5 m
8.0 m
8.5 m
9.0 m
9.5 m
SNUM Max Penetration CG
5 4.56 m
9 7.88 m
12 10.37 m
Min. impact velocity 175 m/s
Max. impact velocity 312 m/s
Min. impact angle 43 deg
Max. impact angle 73 deg


105mm M60 Smoke
Silt-Clay
Silt: Thickness 0.6 m, SNUM 10
Impact Velocity (m/s)
Impact Angle (deg)
2.0 m
2.5 m
3.0 m
3.5 m
4.0 m
SNUM Clay
5
9
12
Penetration CG
1.5 m
2.0 m
2.5 m
3.0 m
3.5 m
4.0 m
4.5 m
5.0 m
5.5 m
6.0 m
6.5 m
7.0 m
7.5 m
8.0 m
8.5 m
9.0 m
9.5 m
SNUM Max Penetration CG
5 4.64 m
9 8.01 m
12 10.55 m
Min. impact velocity 175 m/s
Max. impact velocity 312 m/s
Min. impact angle 43 deg
Max. impact angle 73 deg

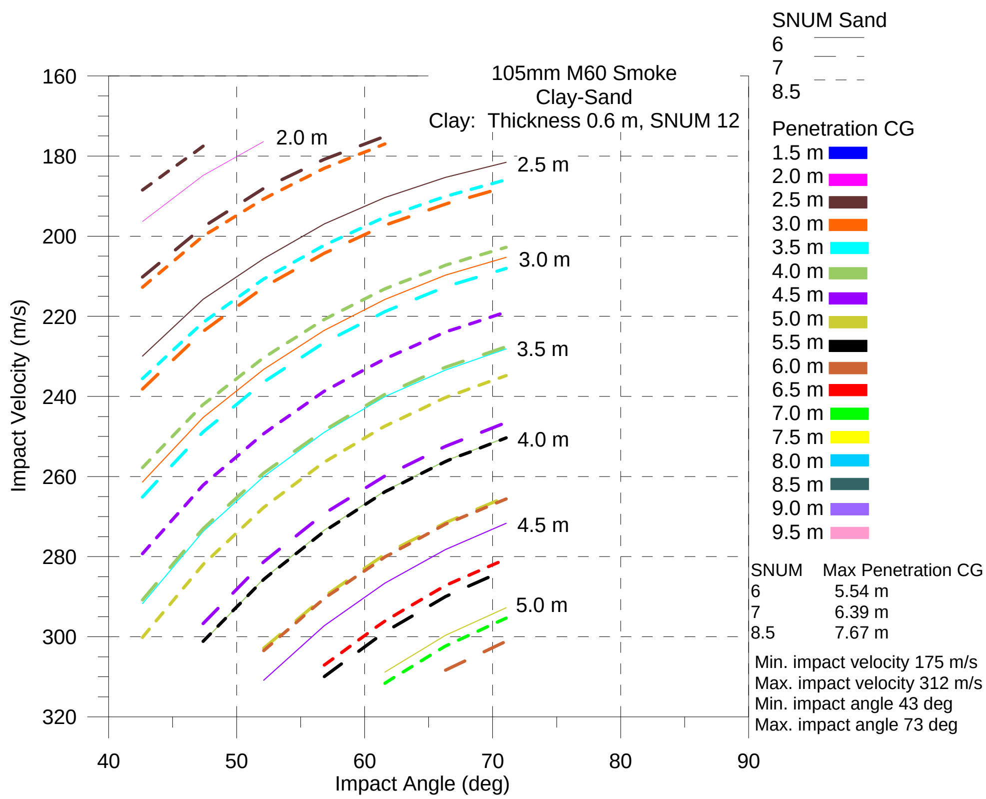
Clay-Sand



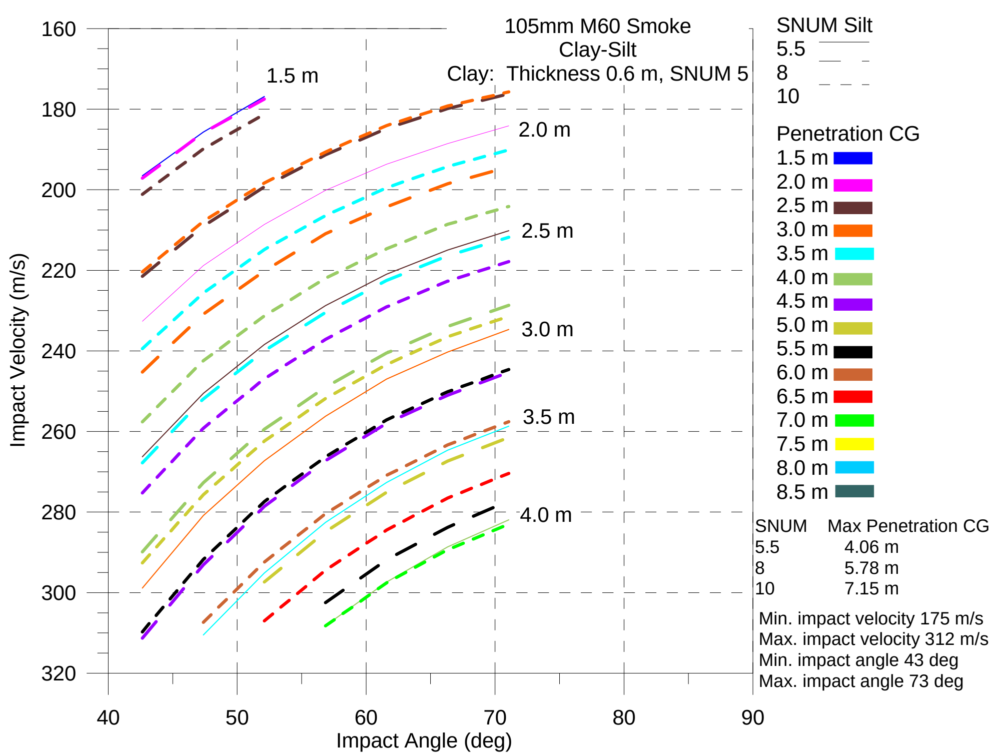
105mm M60 Smoke
Clay-Sand
Clay: Thickness 0.6 m, SNUM 5
1.5 m
2.0 m
2.5 m
3.0 m
3.5 m
4.0 m
Impact Velocity (m/s)
Impact Angle (deg)
160
180
200
220
240
260
280
300
320
40
50
60
70
80
90
SNUM Sand
6
7
8.5
Penetration CG
1.5 m
2.0 m
2.5 m
3.0 m
3.5 m
4.0 m
4.5 m
5.0 m
5.5 m
6.0 m
6.5 m
7.0 m
7.5 m
8.0 m
8.5 m
9.0 m
9.5 m
SNUM Max Penetration CG
6 4.40 m
7 5.08 m
8.5 6.12 m
Min. impact velocity 175 m/s
Max. impact velocity 312 m/s
Min. impact angle 43 deg
Max. impact angle 73 deg

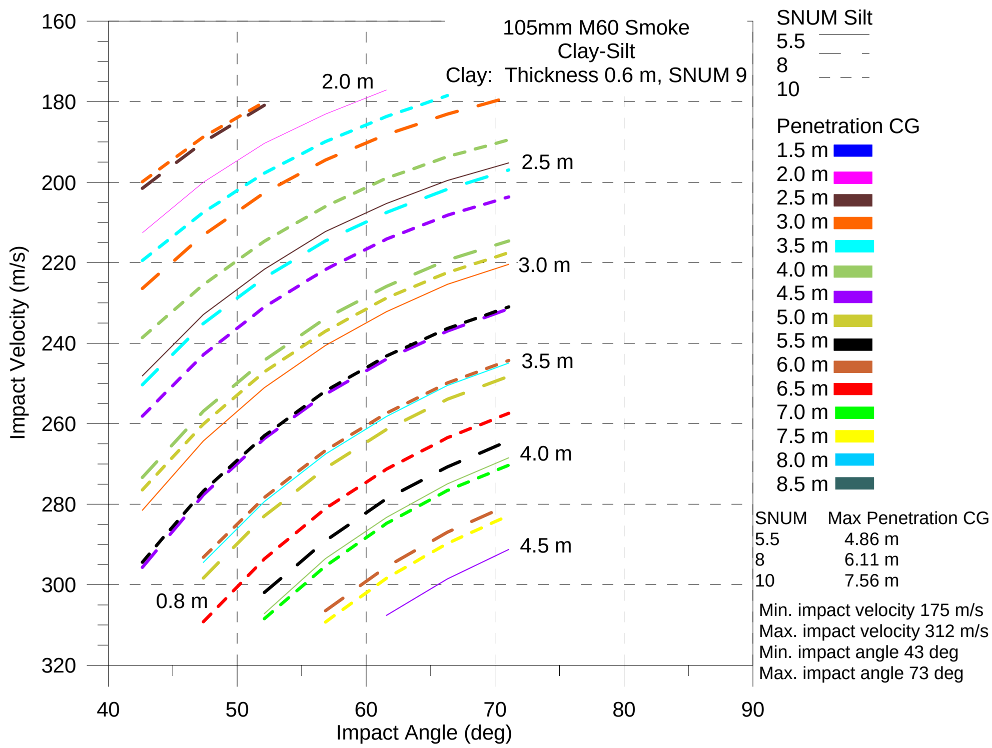


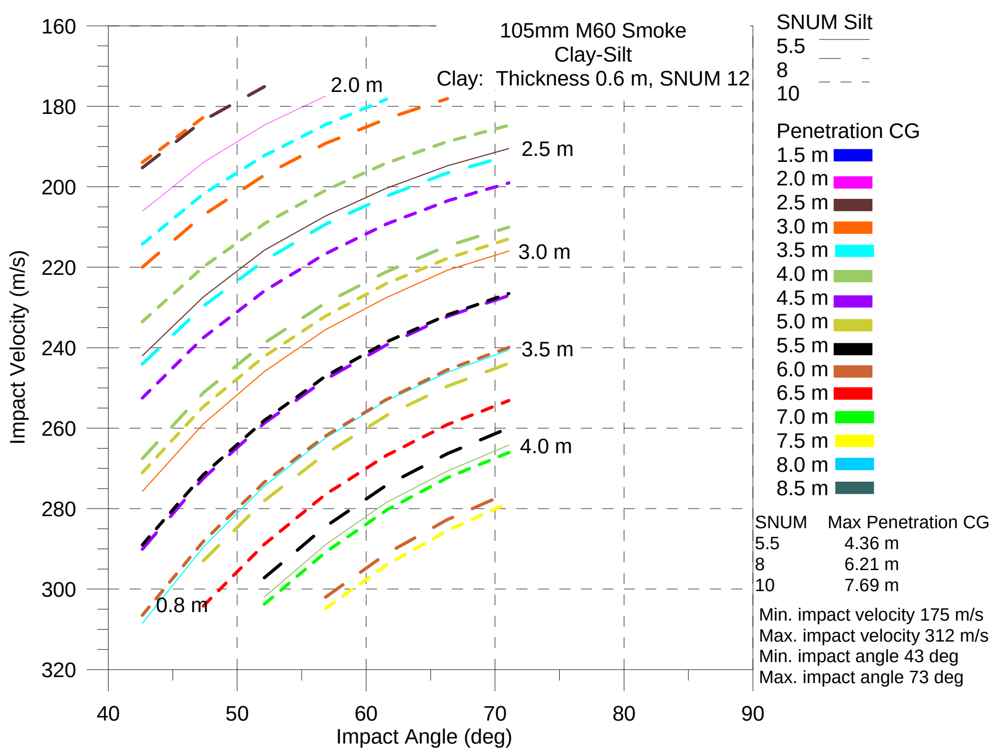
105mm M60 Smoke
Clay-Sand
Clay: Thickness 0.6 m, SNUM 9
2.0 m
2.5 m
3.0 m
3.5 m
4.0 m
4.5 m
5.0 m
Impact Velocity (m/s)
Impact Angle (deg)
160
180
200
220
240
260
280
300
320
40
50
60
70
80
90
SNUM Sand
6
7
8.5
Penetration CG
1.5 m
2.0 m
2.5 m
3.0 m
3.5 m
4.0 m
4.5 m
5.0 m
5.5 m
6.0 m
6.5 m
7.0 m
7.5 m
8.0 m
8.5 m
9.0 m
9.5 m
SNUM Max Penetration CG
6 5.44 m
7 6.28 m
8.5 7.54 m
Min. impact velocity 175 m/s
Max. impact velocity 312 m/s
Min. impact angle 43 deg
Max. impact angle 73 deg


105mm M60 Smoke
Clay-Sand
Clay: Thickness 0.6 m, SNUM 12
SNUM Sand
6
7
8.5
Penetration CG
1.5 m
2.0 m
2.5 m
3.0 m
3.5 m
4.0 m
4.5 m
5.0 m
5.5 m
6.0 m
6.5 m
7.0 m
7.5 m
8.0 m
8.5 m
9.0 m
9.5 m
SNUM Max Penetration CG
6 5.54 m
7 6.39 m
8.5 7.67 m
Min. impact velocity 175 m/s
Max. impact velocity 312 m/s
Min. impact angle 43 deg
Max. impact angle 73 deg
Impact Velocity (m/s)
Impact Angle (deg)

Clay-Silt

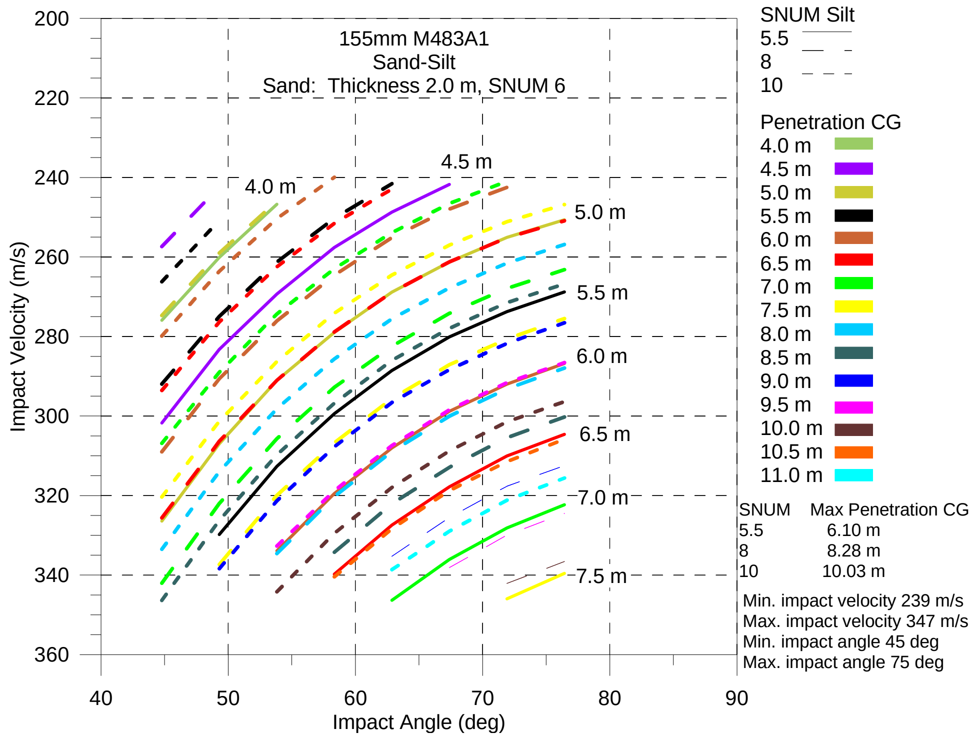

105mm M60 Smoke
Clay-Silt
Clay: Thickness 0.6 m, SNUM 5
SNUM Silt
5.5
8
10
Penetration CG
1.5 m
2.0 m
2.5 m
3.0 m
3.5 m
4.0 m
4.5 m
5.0 m
5.5 m
6.0 m
6.5 m
7.0 m
7.5 m
8.0 m
8.5 m
SNUM Max Penetration CG
5.5 4.06 m
8 5.78 m
10 7.15 m
Min. impact velocity 175 m/s
Max. impact velocity 312 m/s
Min. impact angle 43 deg
Max. impact angle 73 deg
Impact Velocity (m/s)
Impact Angle (deg)

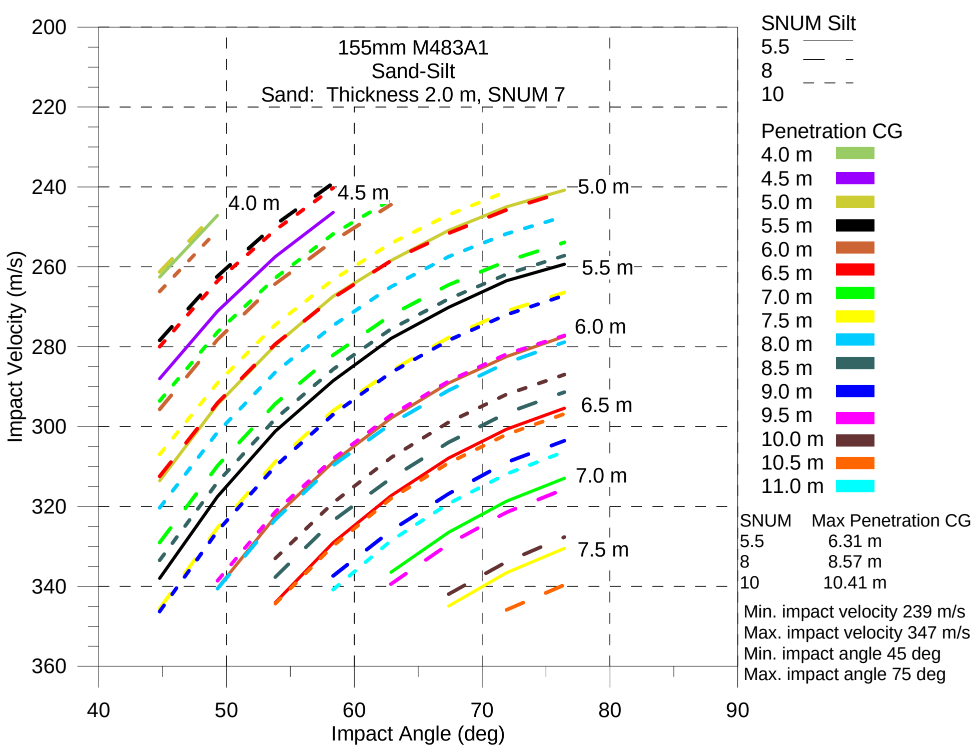

105mm M60 Smoke
Clay-Silt
Clay: Thickness 0.6 m, SNUM 9
SNUM Silt
5.5
8
10
Penetration CG
1.5 m
2.0 m
2.5 m
3.0 m
3.5 m
4.0 m
4.5 m
5.0 m
5.5 m
6.0 m
6.5 m
7.0 m
7.5 m
8.0 m
8.5 m
SNUM Max Penetration CG
5.5 4.86 m
8 6.11 m
10 7.56 m
Min. impact velocity 175 m/s
Max. impact velocity 312 m/s
Min. impact angle 43 deg
Max. impact angle 73 deg
2.0 m
2.5 m
3.0 m
3.5 m
4.0 m
4.5 m
0.8 m
Impact Velocity (m/s)
Impact Angle (deg)
160
180
200
220
240
260
280
300
320
40
50
60
70
80
90

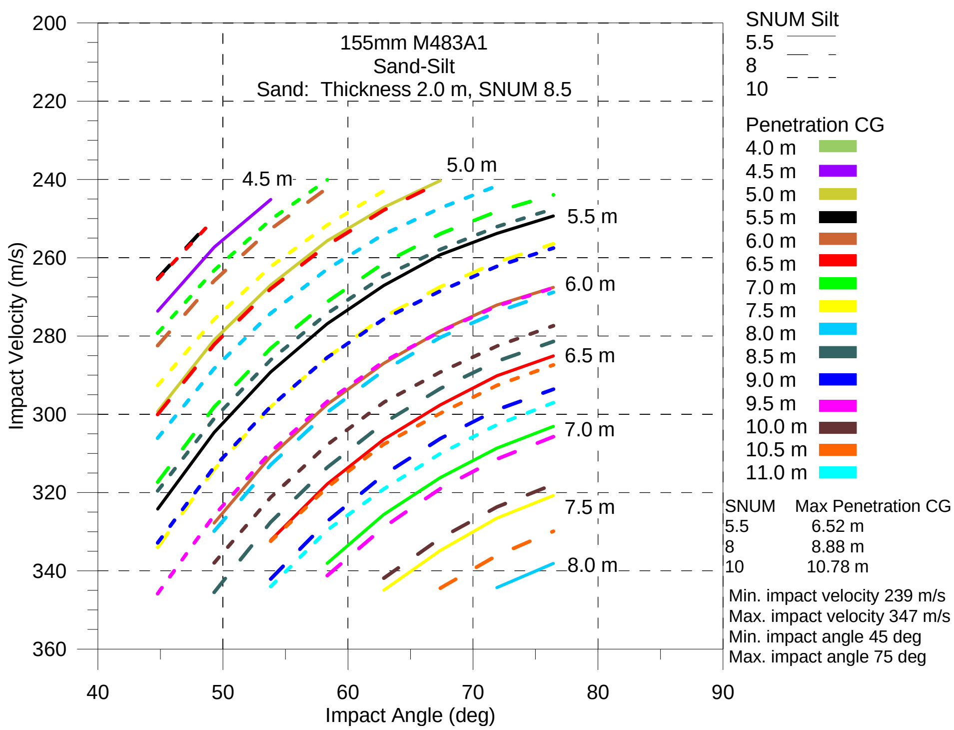

105mm M60 Smoke
Clay-Silt
Clay: Thickness 0.6 m, SNUM 12
SNUM Silt
5.5
8
10
Penetration CG
1.5 m
2.0 m
2.5 m
3.0 m
3.5 m
4.0 m
4.5 m
5.0 m
5.5 m
6.0 m
6.5 m
7.0 m
7.5 m
8.0 m
8.5 m
SNUM Max Penetration CG
5.5 4.36 m
8 6.21 m
10 7.69 m
Min. impact velocity 175 m/s
Max. impact velocity 312 m/s
Min. impact angle 43 deg
Max. impact angle 73 deg
2.0 m
2.5 m
3.0 m
3.5 m
4.0 m
0.8 m
Impact Velocity (m/s)
Impact Angle (deg)
160
180
200
220
240
260
280
300
320
40
50
60
70
80
90

155mm M483A1

Sand-Silt

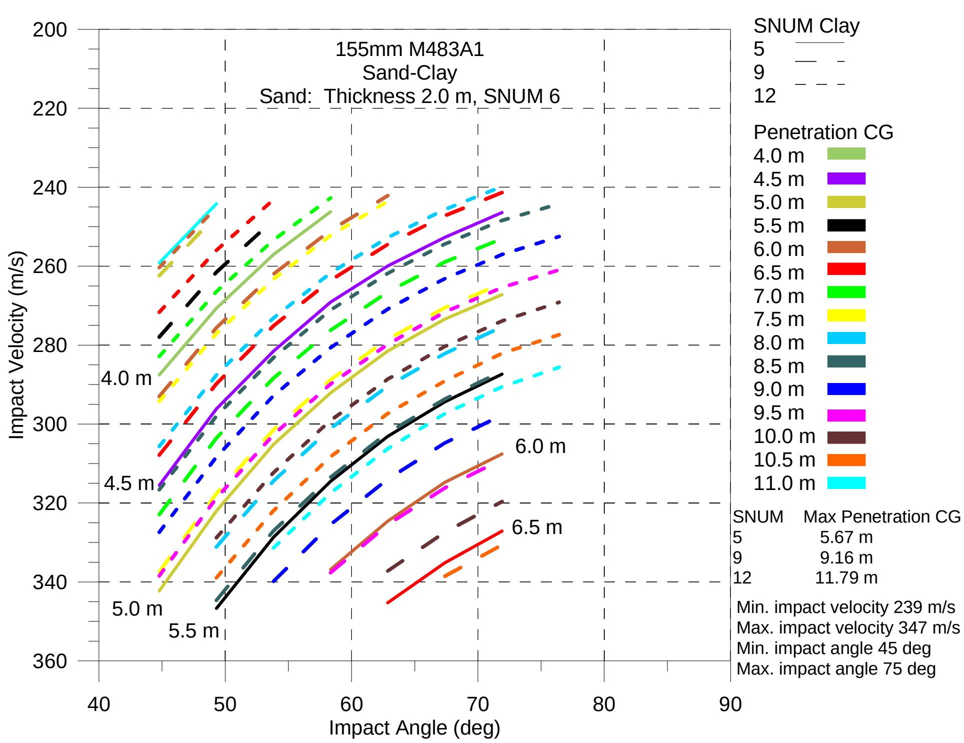




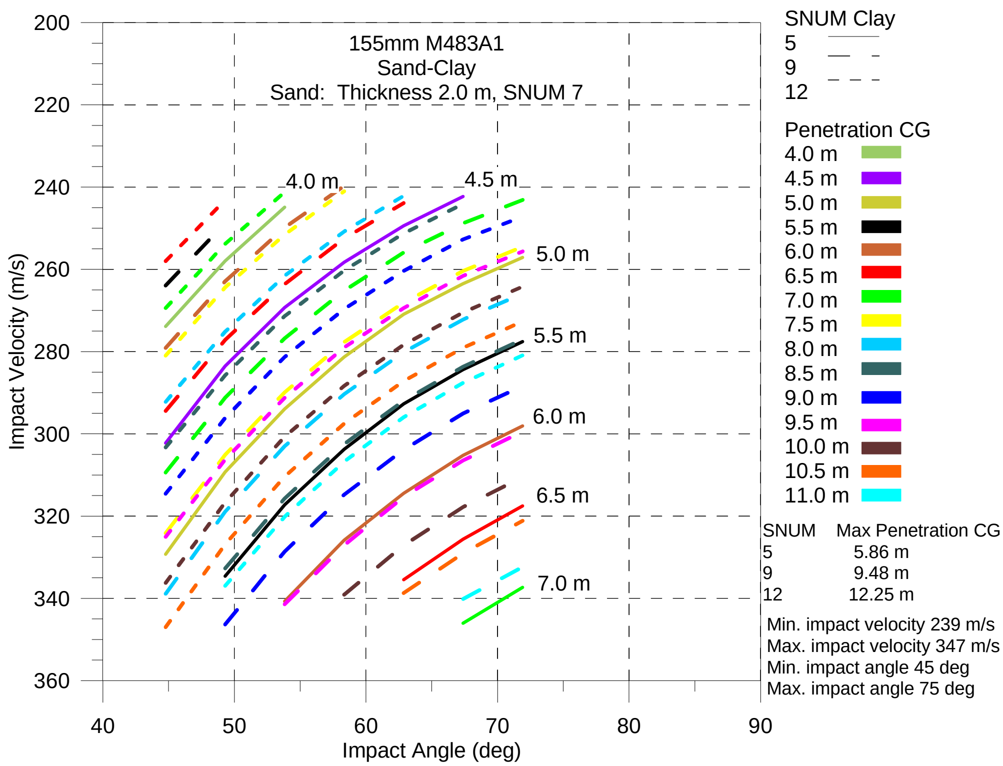


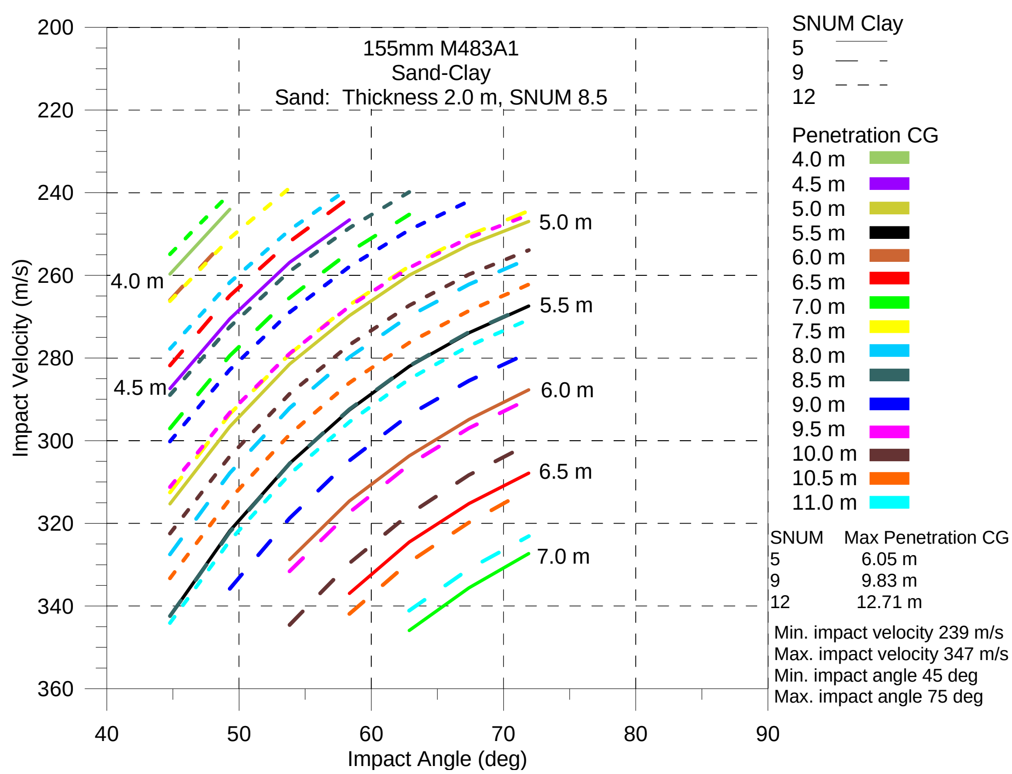
155mm M483A1
Sand-Silt
Sand: Thickness 2.0 m, SNUM 8.5
SNUM Silt
5.5
8
10
Penetration CG
4.0 m
4.5 m
5.0 m
5.5 m
6.0 m
6.5 m
7.0 m
7.5 m
8.0 m
8.5 m
9.0 m
9.5 m
10.0 m
10.5 m
11.0 m
SNUM Max Penetration CG
5.5 6.52 m
8 8.88 m
10 10.78 m
Min. impact velocity 239 m/s
Max. impact velocity 347 m/s
Min. impact angle 45 deg
Max. impact angle 75 deg
Impact Velocity (m/s)
Impact Angle (deg)

Sand-Clay

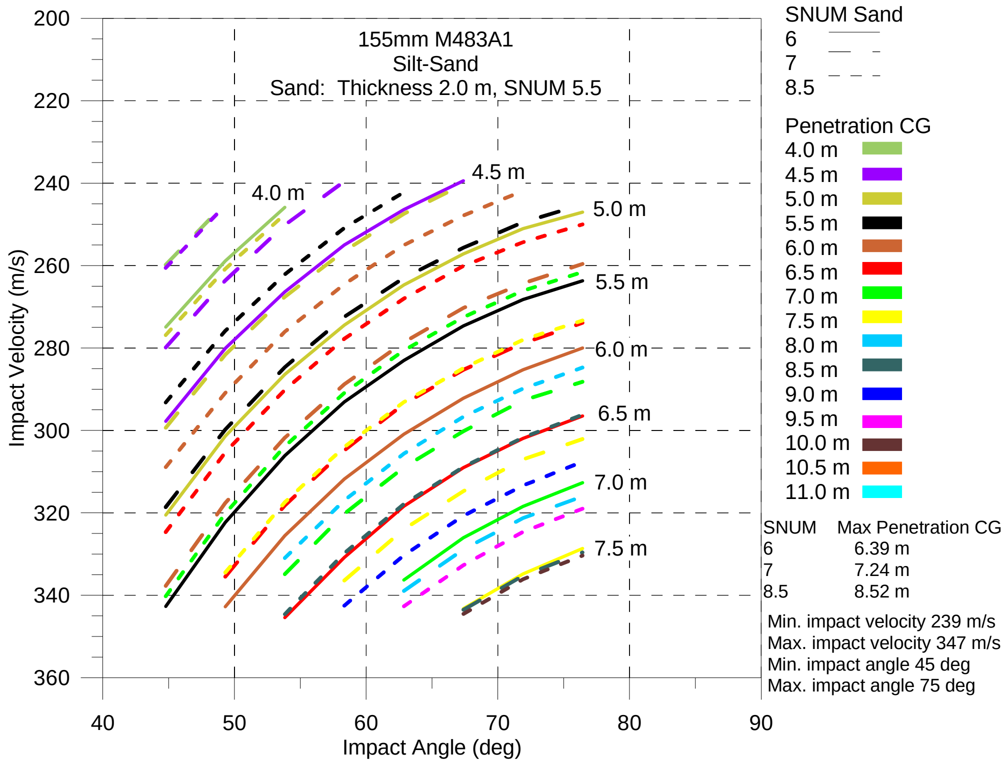


155mm M483A1
Sand-Clay
Sand: Thickness 2.0 m, SNUM 6
SNUM Clay
5
9
12
Penetration CG
4.0 m
4.5 m
5.0 m
5.5 m
6.0 m
6.5 m
7.0 m
7.5 m
8.0 m
8.5 m
9.0 m
9.5 m
10.0 m
10.5 m
11.0 m
SNUM Max Penetration CG
5 5.67 m
9 9.16 m
12 11.79 m
Min. impact velocity 239 m/s
Max. impact velocity 347 m/s
Min. impact angle 45 deg
Max. impact angle 75 deg
Impact Velocity (m/s)
Impact Angle (deg)

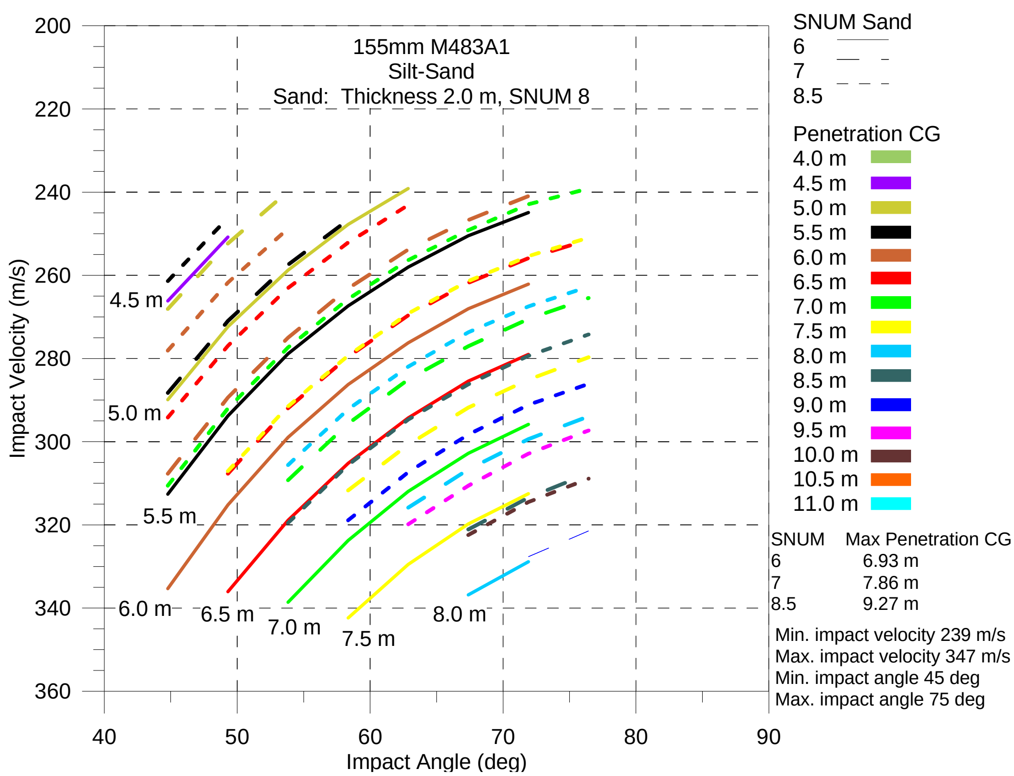

155mm M483A1
Sand-Clay
Sand: Thickness 2.0 m, SNUM 7
Impact Velocity (m/s)
Impact Angle (deg)
4.0 m
4.5 m
5.0 m
5.5 m
6.0 m
6.5 m
7.0 m
SNUM Clay
5
9
12
Penetration CG
4.0 m
4.5 m
5.0 m
5.5 m
6.0 m
6.5 m
7.0 m
7.5 m
8.0 m
8.5 m
9.0 m
9.5 m
10.0 m
10.5 m
11.0 m
SNUM Max Penetration CG
5 5.86 m
9 9.48 m
12 12.25 m
Min. impact velocity 239 m/s
Max. impact velocity 347 m/s
Min. impact angle 45 deg
Max. impact angle 75 deg


155mm M483A1
Sand-Clay
Sand: Thickness 2.0 m, SNUM 8.5
Impact Velocity (m/s)
Impact Angle (deg)
4.0 m
4.5 m
5.0 m
5.5 m
6.0 m
6.5 m
7.0 m
SNUM Clay
5
9
12
Penetration CG
4.0 m
4.5 m
5.0 m
5.5 m
6.0 m
6.5 m
7.0 m
7.5 m
8.0 m
8.5 m
9.0 m
9.5 m
10.0 m
10.5 m
11.0 m
SNUM Max Penetration CG
5 6.05 m
9 9.83 m
12 12.71 m
Min. impact velocity 239 m/s
Max. impact velocity 347 m/s
Min. impact angle 45 deg
Max. impact angle 75 deg

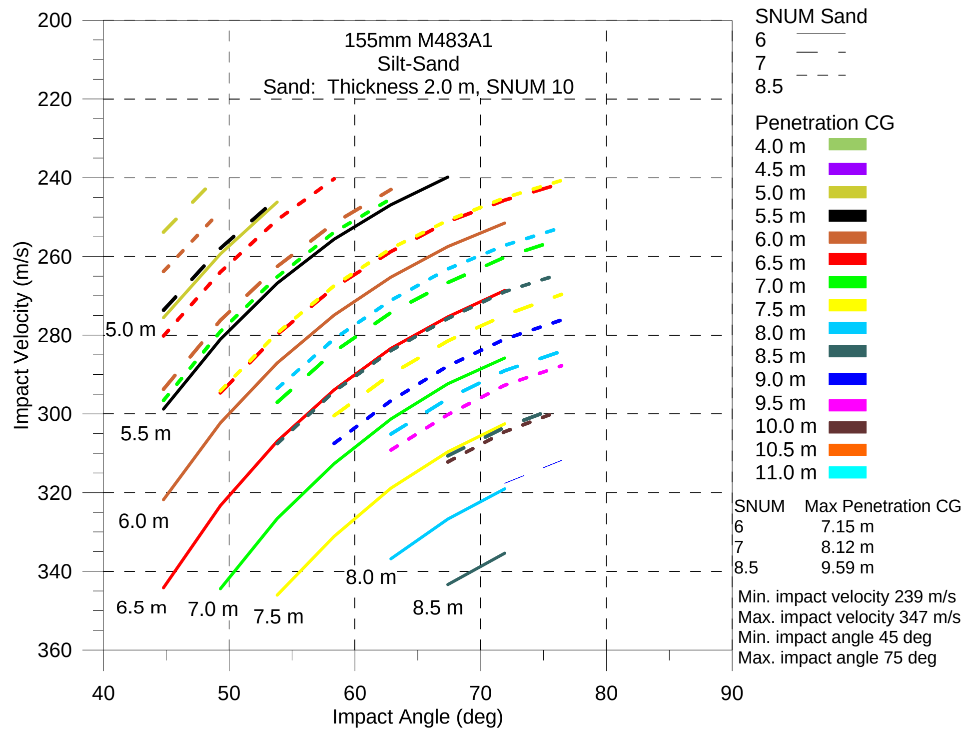
Silt-Sand



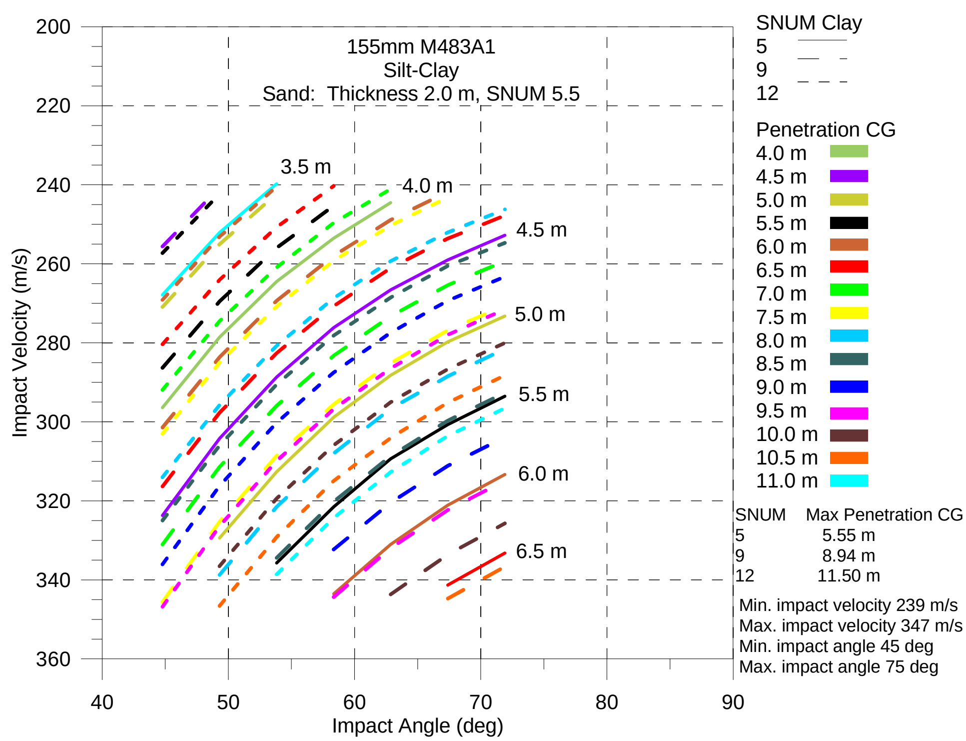
155mm M483A1
Silt-Sand
Sand: Thickness 2.0 m, SNUM 5.5
Impact Velocity (m/s)
Impact Angle (deg)
200
220
240
260
280
300
320
340
360
40
50
60
70
80
90
4.0 m
4.5 m
5.0 m
5.5 m
6.0 m
6.5 m
7.0 m
7.5 m
SNUM Sand
6
7
8.5
Penetration CG
4.0 m
4.5 m
5.0 m
5.5 m
6.0 m
6.5 m
7.0 m
7.5 m
8.0 m
8.5 m
9.0 m
9.5 m
10.0 m
10.5 m
11.0 m
SNUM Max Penetration CG
6 6.39 m
7 7.24 m
8.5 8.52 m
Min. impact velocity 239 m/s
Max. impact velocity 347 m/s
Min. impact angle 45 deg
Max. impact angle 75 deg

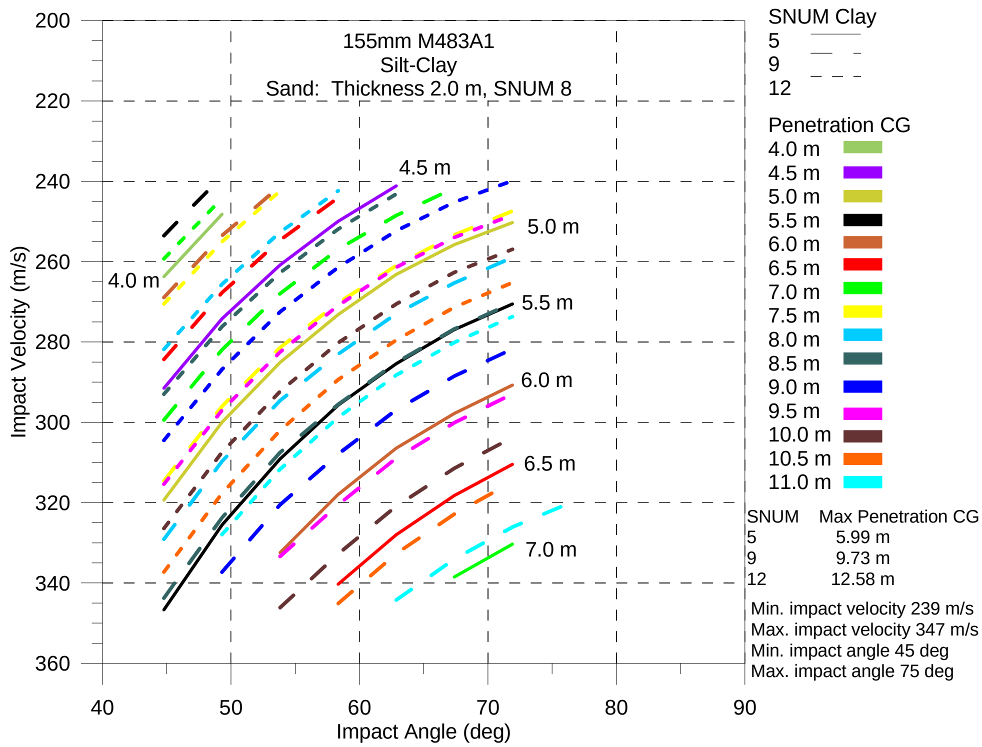


155mm M483A1
Silt-Sand
Sand: Thickness 2.0 m, SNUM 8
Impact Velocity (m/s)
Impact Angle (deg)
200
220
240
260
280
300
320
340
360
40
50
60
70
80
90
4.5 m
5.0 m
5.5 m
6.0 m
6.5 m
7.0 m
7.5 m
8.0 m
SNUM Sand
6
7
8.5
Penetration CG
4.0 m
4.5 m
5.0 m
5.5 m
6.0 m
6.5 m
7.0 m
7.5 m
8.0 m
8.5 m
9.0 m
9.5 m
10.0 m
10.5 m
11.0 m
SNUM Max Penetration CG
6 6.93 m
7 7.86 m
8.5 9.27 m
Min. impact velocity 239 m/s
Max. impact velocity 347 m/s
Min. impact angle 45 deg
Max. impact angle 75 deg

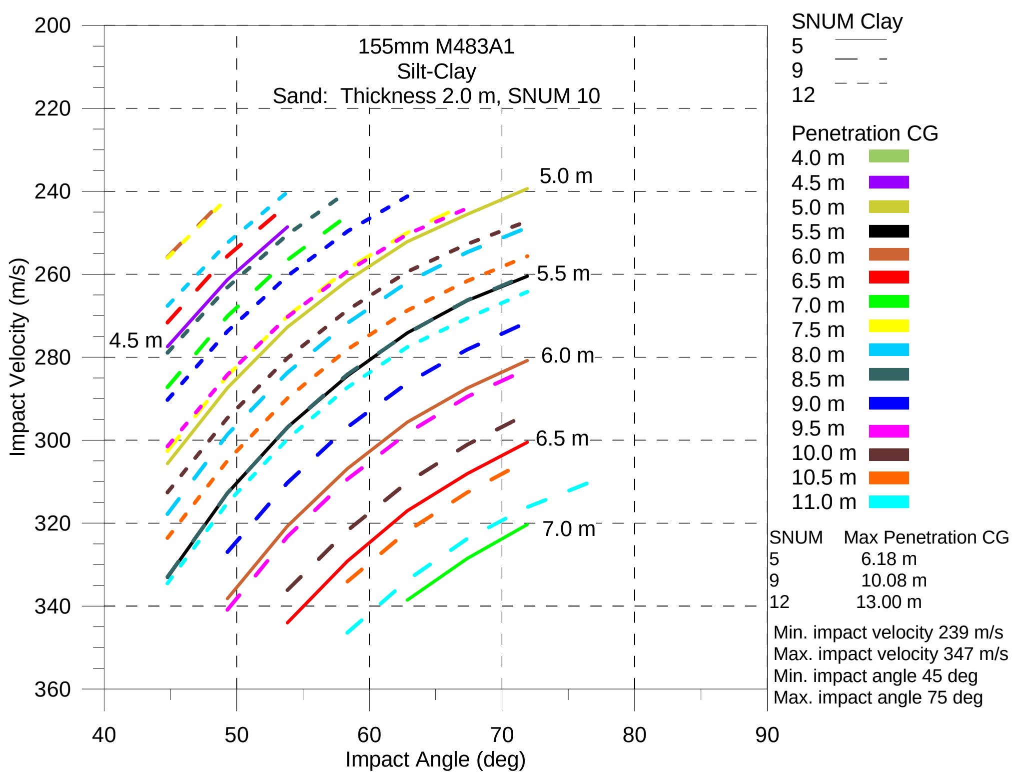

155mm M483A1
Silt-Sand
Sand: Thickness 2.0 m, SNUM 10
Impact Velocity (m/s)
Impact Angle (deg)
SNUM Sand
6
7
8.5
Penetration CG
4.0 m
4.5 m
5.0 m
5.5 m
6.0 m
6.5 m
7.0 m
7.5 m
8.0 m
8.5 m
9.0 m
9.5 m
10.0 m
10.5 m
11.0 m
SNUM Max Penetration CG
6 7.15 m
7 8.12 m
8.5 9.59 m
Min. impact velocity 239 m/s
Max. impact velocity 347 m/s
Min. impact angle 45 deg
Max. impact angle 75 deg

Silt-Clay


155mm M483A1
Silt-Clay
Sand: Thickness 2.0 m, SNUM 5.5
Impact Velocity (m/s)
Impact Angle (deg)
SNUM Clay
5
9
12
Penetration CG
4.0 m
4.5 m
5.0 m
5.5 m
6.0 m
6.5 m
7.0 m
7.5 m
8.0 m
8.5 m
9.0 m
9.5 m
10.0 m
10.5 m
11.0 m
SNUM Max Penetration CG
5 5.55 m
9 8.94 m
12 11.50 m
Min. impact velocity 239 m/s
Max. impact velocity 347 m/s
Min. impact angle 45 deg
Max. impact angle 75 deg

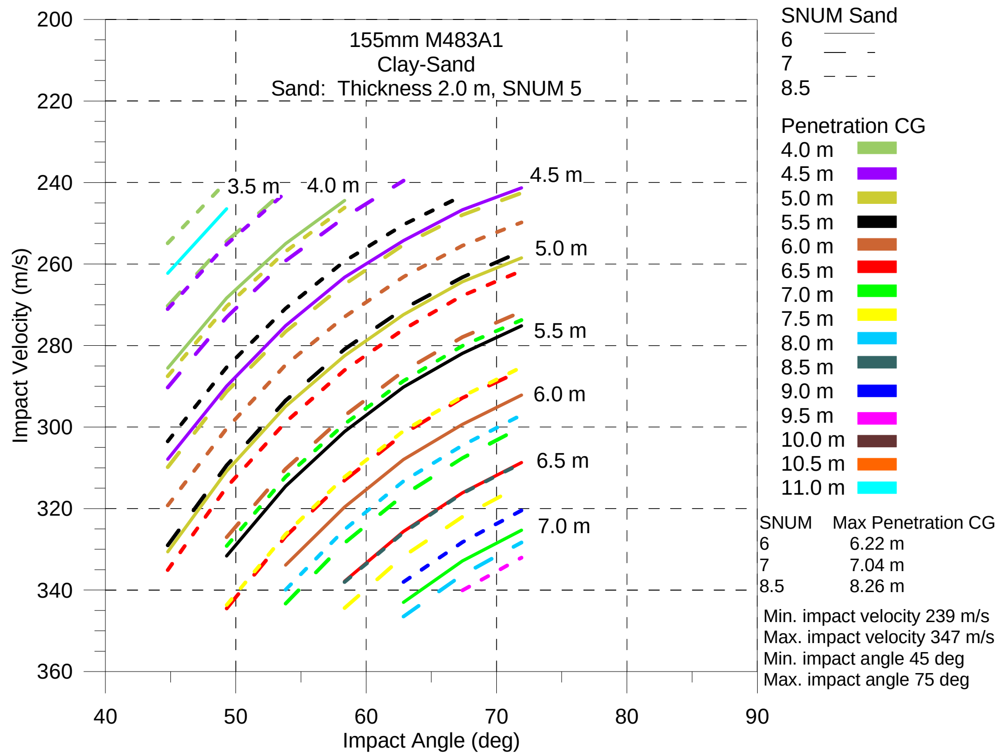


155mm M483A1
Silt-Clay
Sand: Thickness 2.0 m, SNUM 8
Impact Velocity (m/s)
Impact Angle (deg)
4.0 m
4.5 m
5.0 m
5.5 m
6.0 m
6.5 m
7.0 m
SNUM Clay
5
9
12
Penetration CG
4.0 m
4.5 m
5.0 m
5.5 m
6.0 m
6.5 m
7.0 m
7.5 m
8.0 m
8.5 m
9.0 m
9.5 m
10.0 m
10.5 m
11.0 m
SNUM Max Penetration CG
5 5.99 m
9 9.73 m
12 12.58 m
Min. impact velocity 239 m/s
Max. impact velocity 347 m/s
Min. impact angle 45 deg
Max. impact angle 75 deg

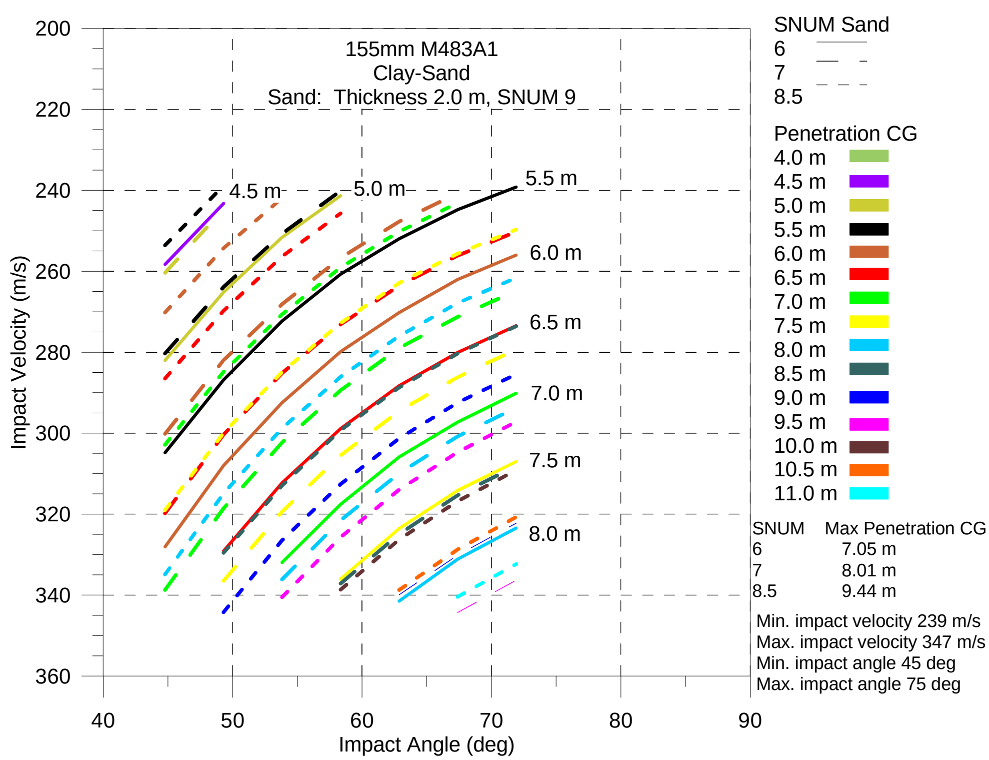


155mm M483A1
Silt-Clay
Sand: Thickness 2.0 m, SNUM 10
Impact Velocity (m/s)
Impact Angle (deg)
4.5 m
5.0 m
5.5 m
6.0 m
6.5 m
7.0 m
SNUM Clay
5
9
12
Penetration CG
4.0 m
4.5 m
5.0 m
5.5 m
6.0 m
6.5 m
7.0 m
7.5 m
8.0 m
8.5 m
9.0 m
9.5 m
10.0 m
10.5 m
11.0 m
SNUM Max Penetration CG
5 6.18 m
9 10.08 m
12 13.00 m
Min. impact velocity 239 m/s
Max. impact velocity 347 m/s
Min. impact angle 45 deg
Max. impact angle 75 deg

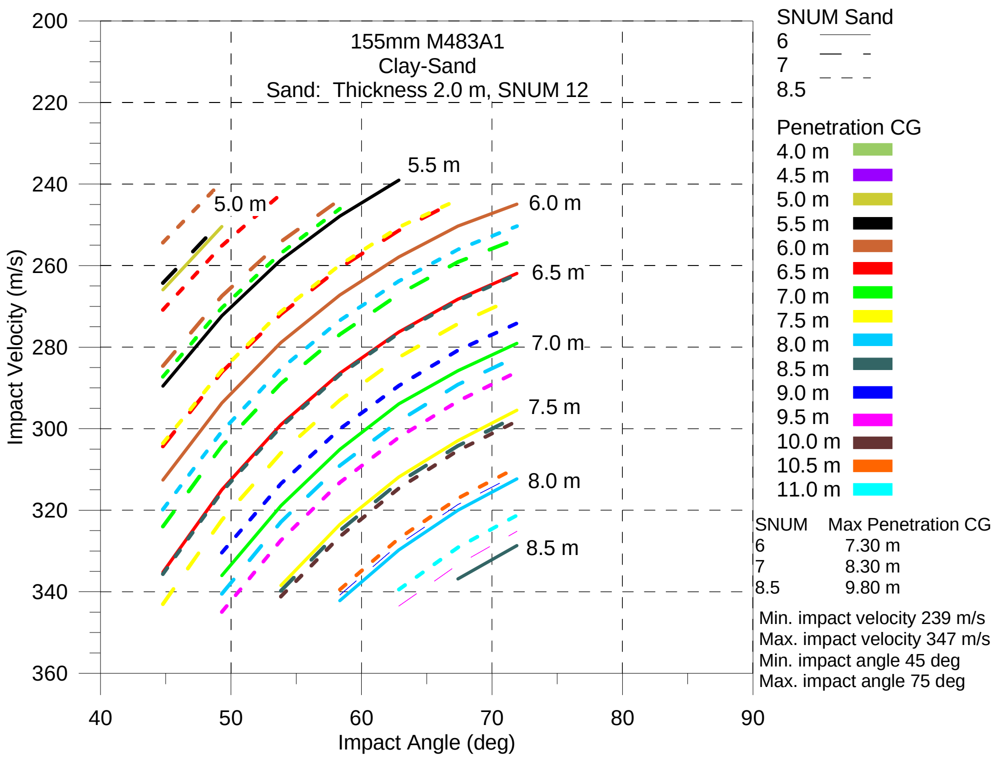
Clay-Sand



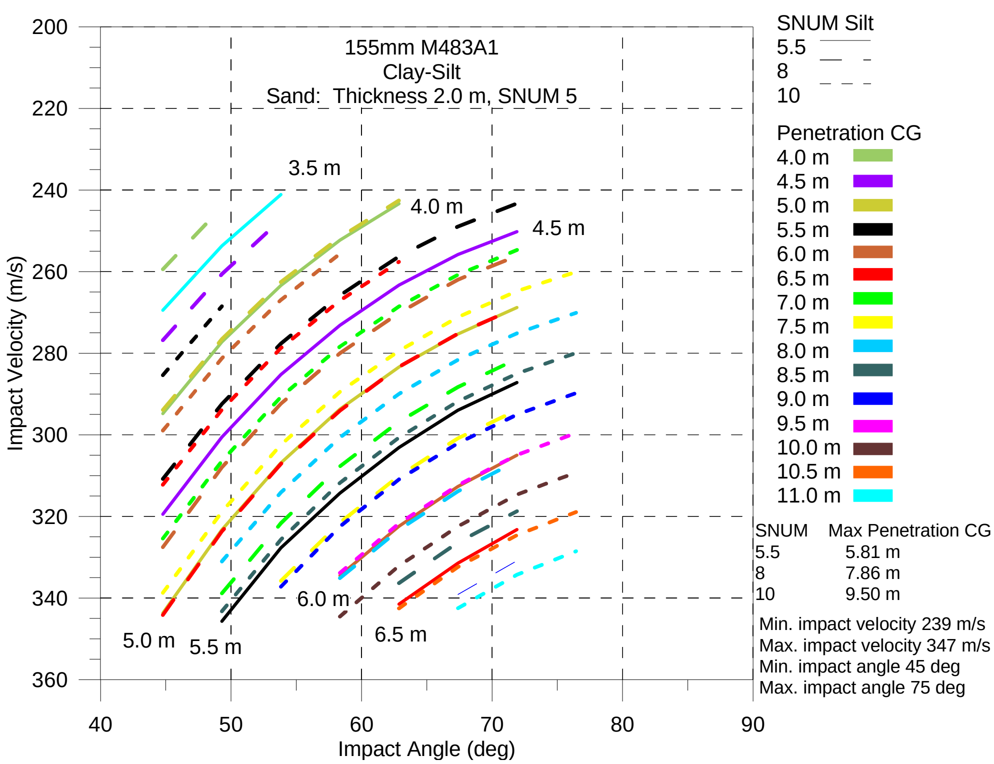
155mm M483A1
Clay-Sand
Sand: Thickness 2.0 m, SNUM 5
3.5 m
4.0 m
4.5 m
5.0 m
5.5 m
6.0 m
6.5 m
7.0 m
Impact Velocity (m/s)
Impact Angle (deg)
SNUM Sand
6
7
8.5
Penetration CG
4.0 m
4.5 m
5.0 m
5.5 m
6.0 m
6.5 m
7.0 m
7.5 m
8.0 m
8.5 m
9.0 m
9.5 m
10.0 m
10.5 m
11.0 m
SNUM Max Penetration CG
6 6.22 m
7 7.04 m
8.5 8.26 m
Min. impact velocity 239 m/s
Max. impact velocity 347 m/s
Min. impact angle 45 deg
Max. impact angle 75 deg

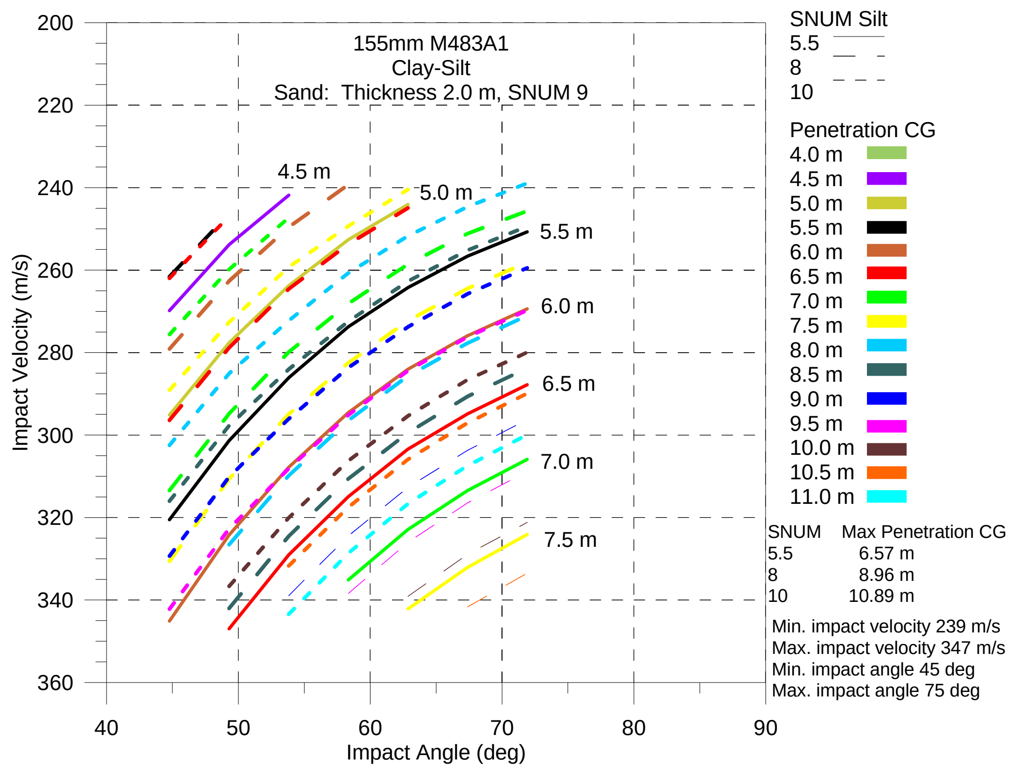


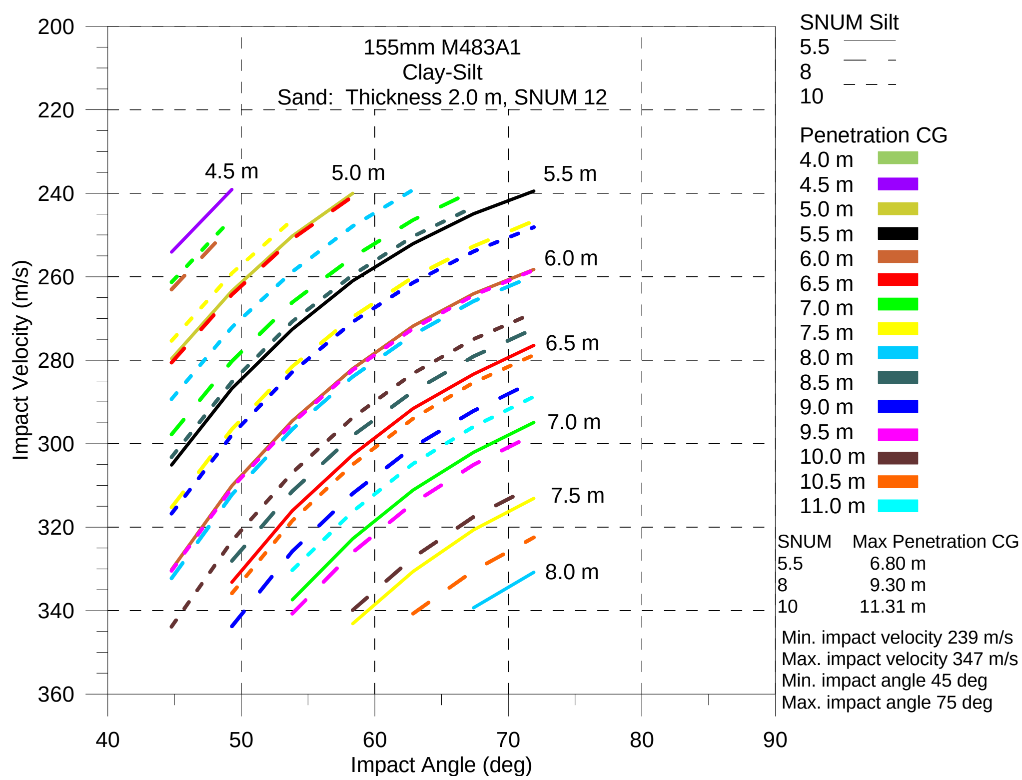
155mm M483A1
Clay-Sand
Sand: Thickness 2.0 m, SNUM 9
4.5 m
5.0 m
5.5 m
6.0 m
6.5 m
7.0 m
7.5 m
8.0 m
Impact Velocity (m/s)
Impact Angle (deg)
SNUM Sand
6
7
8.5
Penetration CG
4.0 m
4.5 m
5.0 m
5.5 m
6.0 m
6.5 m
7.0 m
7.5 m
8.0 m
8.5 m
9.0 m
9.5 m
10.0 m
10.5 m
11.0 m
SNUM Max Penetration CG
6 7.05 m
7 8.01 m
8.5 9.44 m
Min. impact velocity 239 m/s
Max. impact velocity 347 m/s
Min. impact angle 45 deg
Max. impact angle 75 deg


155mm M483A1
Clay-Sand
Sand: Thickness 2.0 m, SNUM 12
Impact Velocity (m/s)
Impact Angle (deg)
5.0 m
5.5 m
6.0 m
6.5 m
7.0 m
7.5 m
8.0 m
8.5 m
SNUM Sand
6
7
8.5
Penetration CG
4.0 m
4.5 m
5.0 m
5.5 m
6.0 m
6.5 m
7.0 m
7.5 m
8.0 m
8.5 m
9.0 m
9.5 m
10.0 m
10.5 m
11.0 m
SNUM Max Penetration CG
6 7.30 m
7 8.30 m
8.5 9.80 m
Min. impact velocity 239 m/s
Max. impact velocity 347 m/s
Min. impact angle 45 deg
Max. impact angle 75 deg

Clay-Silt


155mm M483A1
Clay-Silt
Sand: Thickness 2.0 m, SNUM 5
Impact Velocity (m/s)
Impact Angle (deg)
3.5 m
4.0 m
4.5 m
5.0 m
5.5 m
6.0 m
6.5 m
SNUM Silt
5.5
8
10
Penetration CG
4.0 m
4.5 m
5.0 m
5.5 m
6.0 m
6.5 m
7.0 m
7.5 m
8.0 m
8.5 m
9.0 m
9.5 m
10.0 m
10.5 m
11.0 m
SNUM Max Penetration CG
5.5 5.81 m
8 7.86 m
10 9.50 m
Min. impact velocity 239 m/s
Max. impact velocity 347 m/s
Min. impact angle 45 deg
Max. impact angle 75 deg


155mm M483A1
Clay-Silt
Sand: Thickness 2.0 m, SNUM 9
Impact Velocity (m/s)
Impact Angle (deg)
4.5 m
5.0 m
5.5 m
6.0 m
6.5 m
7.0 m
7.5 m
SNUM Silt
5.5
8
10
Penetration CG
4.0 m
4.5 m
5.0 m
5.5 m
6.0 m
6.5 m
7.0 m
7.5 m
8.0 m
8.5 m
9.0 m
9.5 m
10.0 m
10.5 m
11.0 m
SNUM Max Penetration CG
5.5 6.57 m
8 8.96 m
10 10.89 m
Min. impact velocity 239 m/s
Max. impact velocity 347 m/s
Min. impact angle 45 deg
Max. impact angle 75 deg


155mm M483A1
Clay-Silt
Sand: Thickness 2.0 m, SNUM 12
Impact Velocity (m/s)
Impact Angle (deg)
4.5 m
5.0 m
5.5 m
6.0 m
6.5 m
7.0 m
7.5 m
8.0 m
SNUM Silt
5.5
8
10
Penetration CG
4.0 m
4.5 m
5.0 m
5.5 m
6.0 m
6.5 m
7.0 m
7.5 m
8.0 m
8.5 m
9.0 m
9.5 m
10.0 m
10.5 m
11.0 m
SNUM Max Penetration CG
5.5 6.80 m
8 9.30 m
10 11.31 m
Min. impact velocity 239 m/s
Max. impact velocity 347 m/s
Min. impact angle 45 deg
Max. impact angle 75 deg